**Smart Intelligent Energy Insight System (SIEIS)**

Course: AAI-530  
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# Abstract

The Smart Intelligent Energy Insight System (SIEIS) is a distributed data engineering and analytics platform for streaming environmental telemetry. The system integrates event-driven ingestion, dual-path persistence, API-based serving, dashboard-based observability, and scheduled model lifecycle operations. The objective is to support both low-latency operational monitoring and long-term analytical and ML workflows using a unified architecture.

# 1. Introduction

Indoor environments influence comfort, productivity, and health. Modern IoT deployments stream temperature, humidity, ambient light, and device voltage from distributed motes. Practical systems must support heterogeneous data rates, near real-time visibility, and durable historical retention for analytics and model training. SIEIS addresses these needs by combining stream processing, time-series storage, object storage, and a lightweight ML pipeline in a containerized architecture.

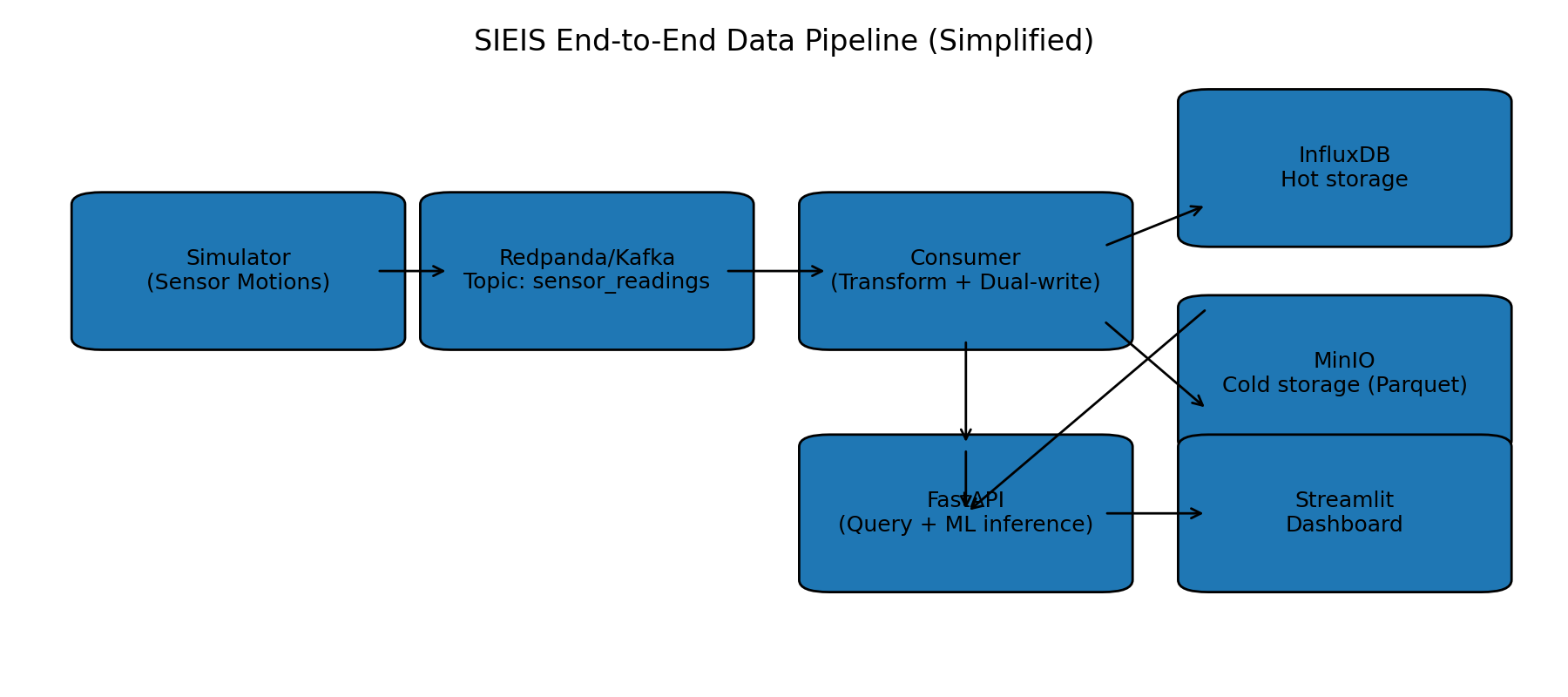
## 1.1 Project Objectives

* Implement an end-to-end streaming pipeline for environmental telemetry with reliable ingestion and transformation.
* Support a dual persistence strategy: hot storage for low-latency queries and cold storage for durable analytics.
* Expose APIs for health checks, time-series queries, and machine learning inference.
* Provide a dashboard for operational visibility and exploratory analytics.
* Automate simulator management and periodic model retraining.

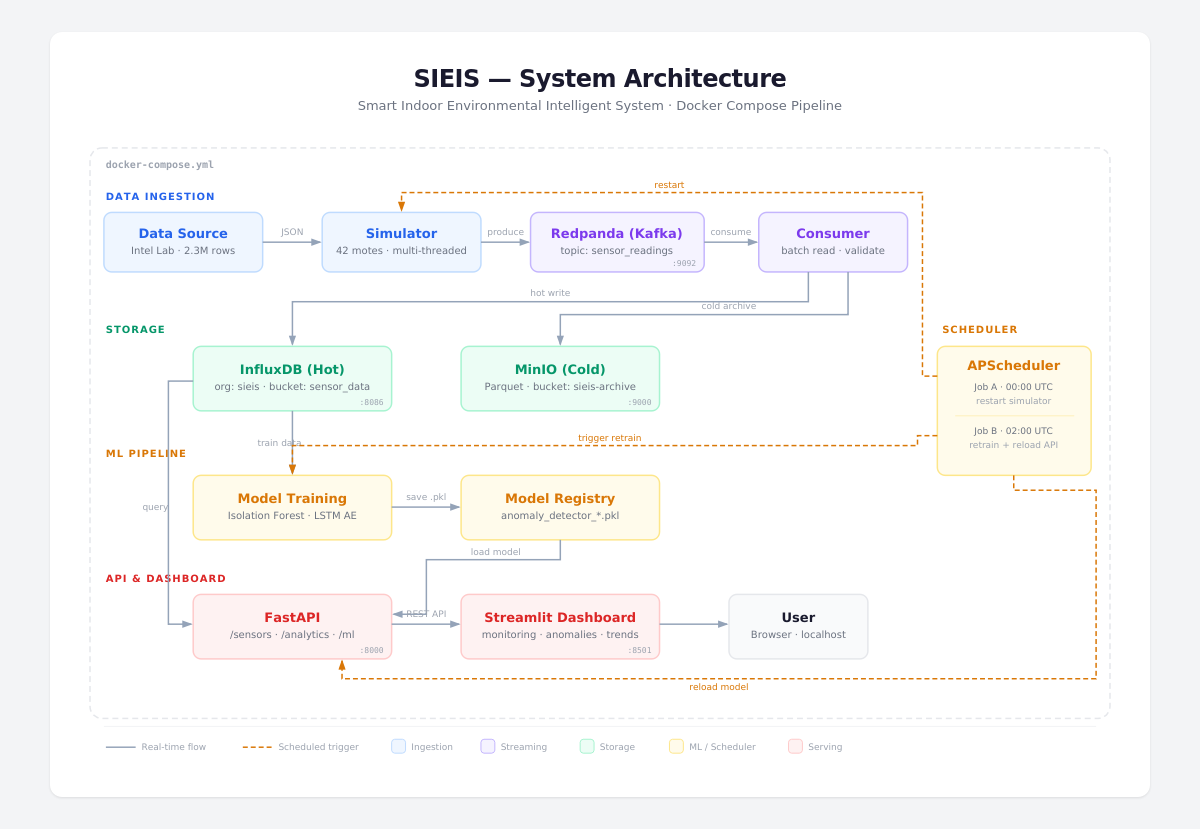
# 2. System Architecture

## 2.1 Architectural Pattern

SIEIS follows a dual-write architecture. The hot path persists readings into InfluxDB to enable low-latency monitoring and interactive queries. The cold path archives readings into MinIO as Parquet files to support durable storage, batch analytics, and model training. A serving layer (FastAPI) and observability layer (Streamlit) consume these stores, while a scheduler coordinates simulator restarts and model lifecycle operations.



*Figure 1. Simplified end-to-end SIEIS data pipeline.*



*Figure 2. SIEIS system architecture (from project repository).*

## 2.2 Services and Exposed Ports

Table 1 lists the containerized services and their externally exposed ports when running via Docker Compose.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Service | Container | Host Port(s) | Internal Address | Verification |
| Redpanda (Kafka broker) | sieis-redpanda | 19092 (host clients), 9092 | redpanda:9092 | docker exec sieis-redpanda rpk cluster info |
| Redpanda Console | sieis-console | 8080 | redpanda-console:8080 | Open http://localhost:8080 |
| InfluxDB | sieis-influxdb3 | 8086 | influxdb3:8086 | GET http://localhost:8086/health |
| MinIO API | sieis-minio | 9000 | minio:9000 | GET http://localhost:9000/minio/health/live |
| MinIO Console | sieis-minio | 9001 | minio:9001 | Open http://localhost:9001 |
| FastAPI | sieis-api | 8000 | sieis-api:8000 | GET http://localhost:8000/api/v1/health |
| Streamlit Dashboard | sieis-dashboard | 8501 | sieis-dashboard:8501 | Open http://localhost:8501 |
| Scheduler | sieis-scheduler | — | internal only | docker logs sieis-scheduler |

*Table 1. SIEIS services and ports (Docker Compose).*

# 3. Data Description and Preparation

SIEIS uses historical environmental telemetry (originally timestamped in 2004) transformed into a real-time compatible timeline for ingestion and hot-storage acceptance. Each record contains: original date and time, epoch identifier, mote ID, and sensor readings (temperature, humidity, light, voltage). A derived updated\_timestamp maps original timestamps into a recent time window to prevent future-dated writes.

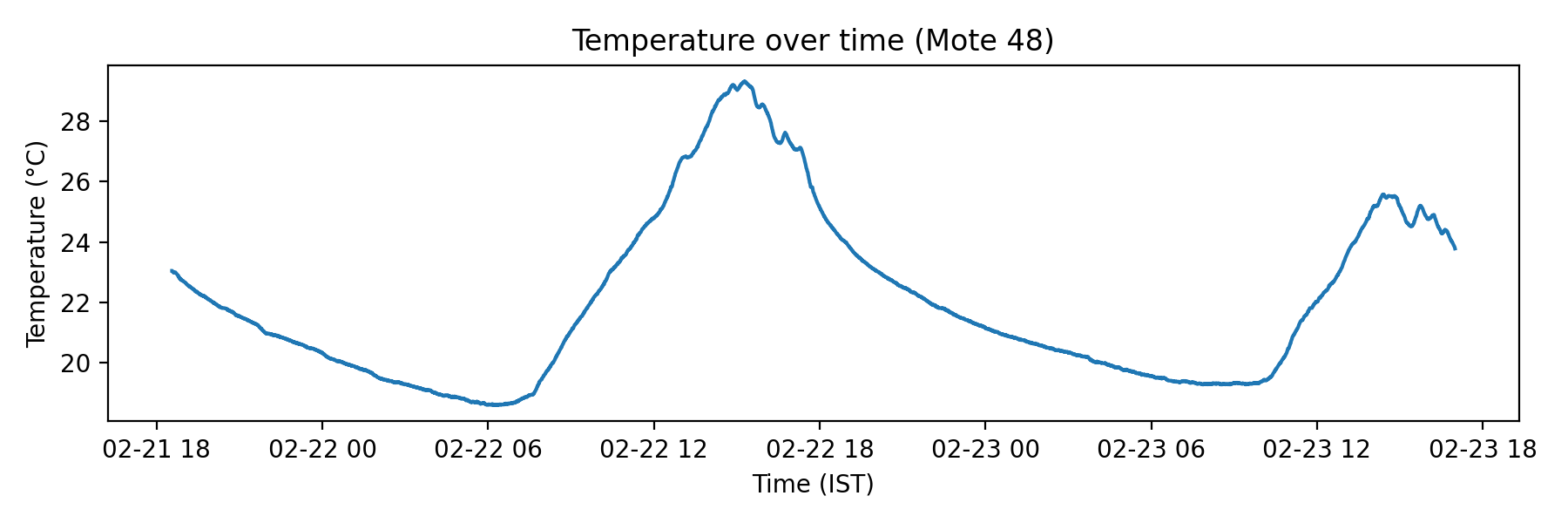
## 3.1 Dataset Summary

|  |  |
| --- | --- |
| Records (historical\_data) | 1,850,934 |
| Unique motes | 58 |
| Updated timestamp range (UTC) | 2026-01-31 19:03 to 2026-02-23 11:30 |
| Primary sensor features | temperature, humidity, light, voltage |
| ML time features | hour, day\_of\_week |

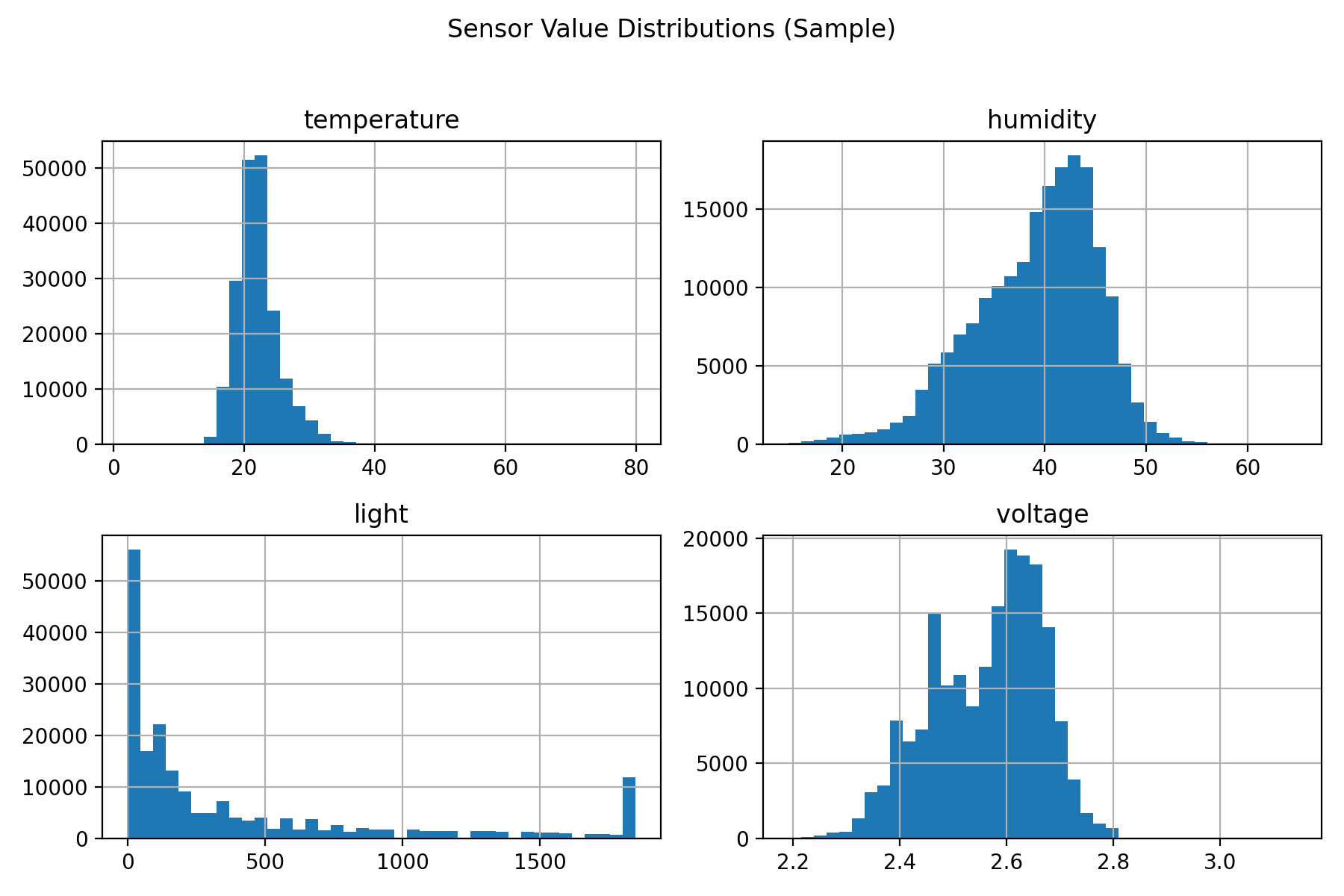
*Table 2. Dataset summary used for analysis in this report.*

## 3.2 Exploratory Data Analysis

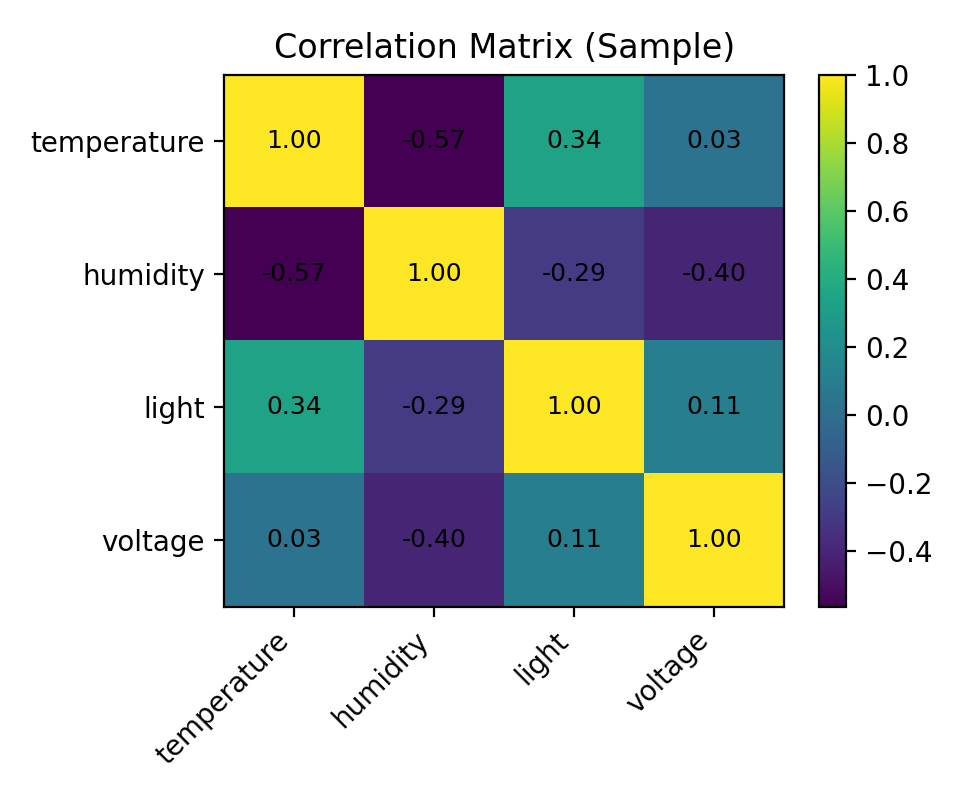
Exploratory analysis was performed on a random sample after applying basic sensor bounds consistent with physical plausibility. Figures 3–5 summarize typical temporal behavior, marginal distributions, and pairwise correlations.



*Figure 3. Temperature time series example for a single mote (IST).*



*Figure 4. Marginal distributions of sensor features (sample).*



*Figure 5. Correlation matrix for sensor features (sample).*

# 4. Machine Learning: Anomaly Detection

The system applies unsupervised anomaly detection to identify unusual readings that may indicate sensor faults, environmental events, or data quality issues. With no anomaly labels available, an Isolation Forest model learns the normal operating region of the feature space and assigns anomaly scores to new observations.

## 4.1 Feature Engineering

The anomaly detector uses sensor features (temperature, humidity, light, voltage) and time-derived features (hour of day and day of week) computed from updated\_timestamp. Missing values are imputed using feature medians after range filtering.

## 4.2 Training Configuration

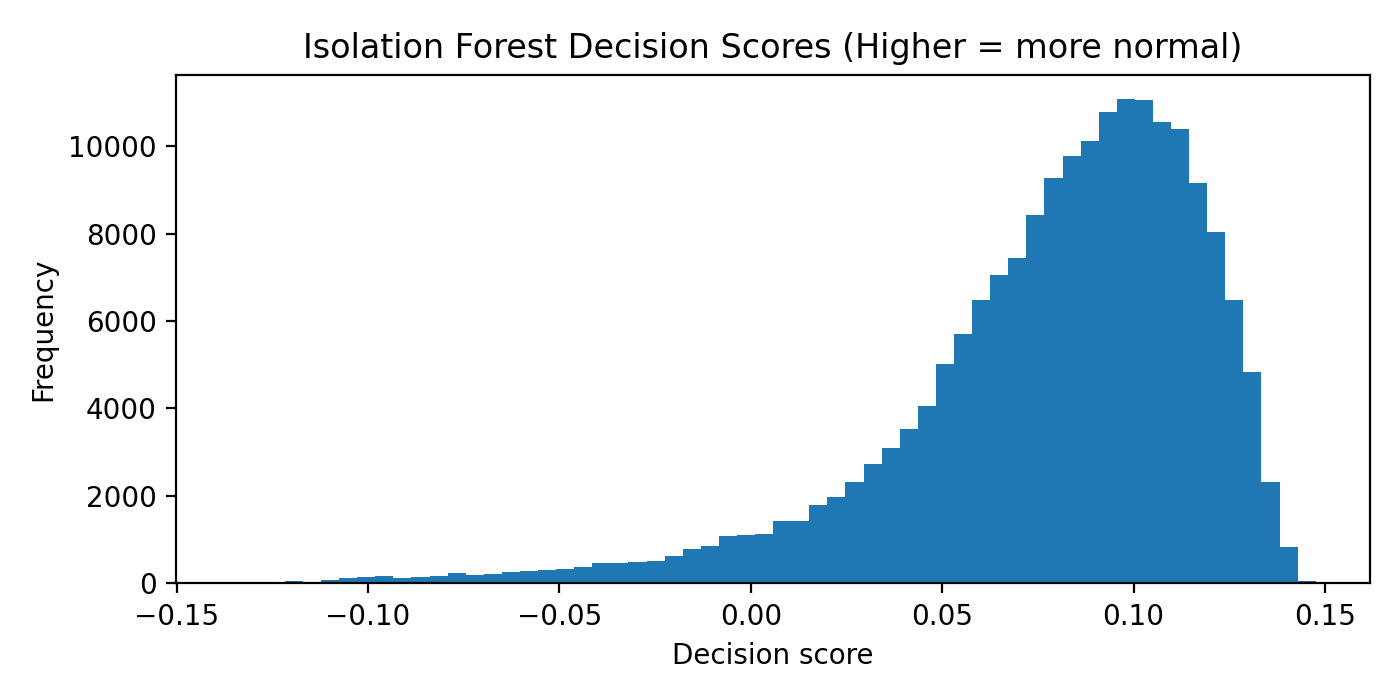
An Isolation Forest is trained with StandardScaler preprocessing. The contamination parameter is set to 0.05 (expected 5% outlier fraction). Training was performed on a 200,000-row sample for computational efficiency.

|  |  |
| --- | --- |
| Training samples | 188,013 |
| Features | temperature, humidity, light, voltage, hour, day\_of\_week |
| Contamination | 0.05 |
| Trees (n\_estimators) | 150 |
| Anomalies detected | 9,401 (5.00%) |
| Decision score mean ± std | 0.0789 ± 0.0404 |

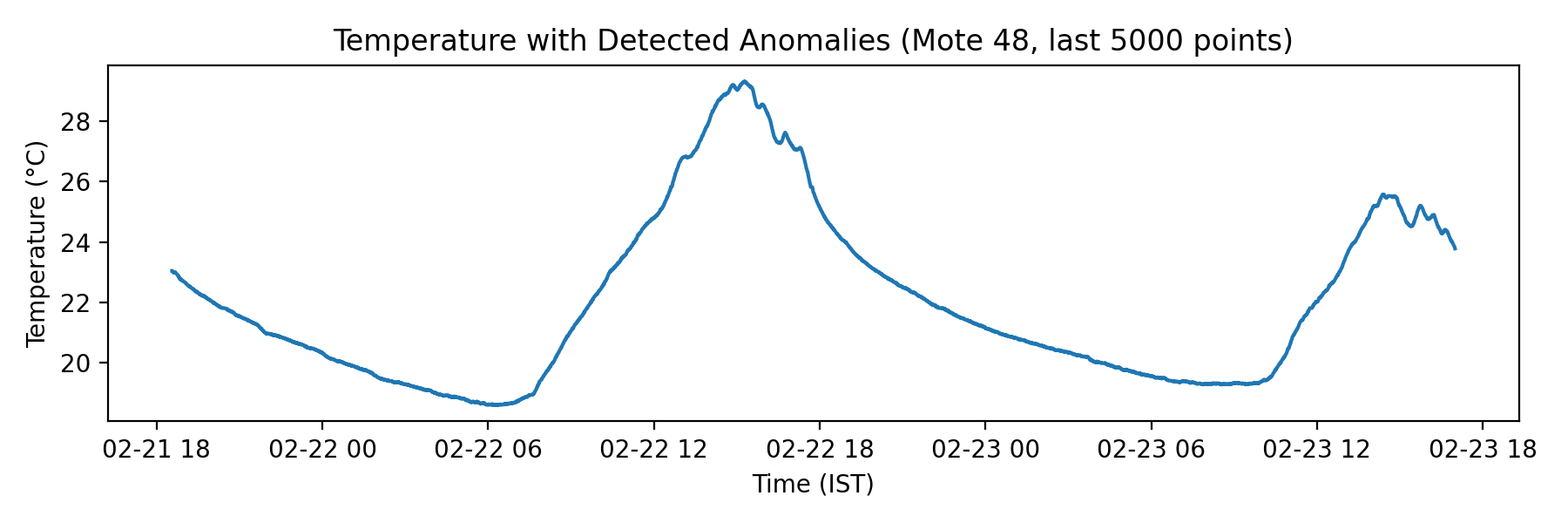
*Table 3. Isolation Forest training configuration and summary metrics.*

## 4.3 Results and Visualization

Figure 6 shows the distribution of decision scores (higher indicates more normal behavior). Figure 7 overlays detected anomalies on a mote’s temperature series to illustrate how the model highlights unusual points in context.



*Figure 6. Distribution of Isolation Forest decision scores (sample).*



*Figure 7. Example anomalies highlighted on temperature (single mote).*

# 5. Deployment, Observability, and Operations

SIEIS is deployed locally via Docker Compose, including the simulator, message broker, consumer, hot and cold stores, API server, dashboard, and scheduler. Operational health is verified via service health endpoints, broker tooling, and container logs. The Streamlit dashboard provides live telemetry visualization and supports interactive inspection of stored data and ML inference results.

## 5.1 Automation and Model Lifecycle

A scheduler service coordinates recurring tasks such as restarting the simulator and retraining the anomaly detector. After training, the model artifact is saved and can be reloaded into the API service for online inference, enabling a practical MLOps loop within the same containerized environment.

# 6. Limitations and Future Work

* Ground-truth anomaly labels are not available; evaluation relies on qualitative inspection and score distributions.
* The current model treats each record independently; future work could incorporate temporal models (e.g., autoencoders) for sequence anomalies.
* Per-mote personalization could improve sensitivity by training separate models or adding mote identifiers as features.
* Security hardening is required for production: secret management, authentication, TLS, and role-based access control.

# 7. Conclusion

SIEIS demonstrates an end-to-end IoT data engineering and analytics platform integrating streaming ingestion, dual-path storage, API-based serving, dashboard observability, and scheduled ML lifecycle operations. The architecture supports both real-time monitoring and durable analytics, while the anomaly detection pipeline provides a practical mechanism to surface unusual sensor behavior without labeled data.

# References

1. Liu, F. T., Ting, K. M., & Zhou, Z.-H. (2008). Isolation Forest. In Proceedings of the 2008 IEEE International Conference on Data Mining.
2. Kreps, J., Narkhede, N., & Rao, J. (2011). Kafka: A Distributed Messaging System for Log Processing. Proceedings of NetDB.
3. InfluxData. (n.d.). InfluxDB documentation. Retrieved 2026-02-26.
4. MinIO, Inc. (n.d.). MinIO documentation. Retrieved 2026-02-26.

# Appendix A: Code Base

This appendix contains the consolidated code base used to implement the Smart Intelligent Energy Insight System (SIEIS). Listings are organized by repository-relative path.

|  |  |  |
| --- | --- | --- |
| File | Type | Size (KB) |
| .env.example | example | 2.1 |
| Dockerfile.api | api | 0.2 |
| Dockerfile.consumer | consumer | 0.4 |
| Dockerfile.dashboard | dashboard | 0.3 |
| Dockerfile.scheduler | scheduler | 1.6 |
| Dockerfile.simulator | simulator | 0.4 |
| Documentation/QUICKSTART.md | md | 2.9 |
| README.md | md | 14.2 |
| data/.checkpoint\_historical.json | json | 0.2 |
| data/raw/mote\_locs.txt | txt | 0.5 |
| data/realtime\_mapping/README.md | md | 6.7 |
| data/realtime\_mapping/preview\_mapping.py | py | 5.3 |
| data/realtime\_mapping/transform\_to\_realtime.py | py | 8.9 |
| data/realtime\_mapping/validate\_output.py | py | 6.7 |
| docker-compose.yml | yml | 8.5 |
| pytest.ini | ini | 0.4 |
| requirements.txt | txt | 0.5 |
| scripts/check\_kafka\_messages.py | py | 0.7 |
| scripts/check\_latest\_timestamps.py | py | 1.2 |
| scripts/clear\_storage.py | py | 7.0 |
| scripts/compact\_minio\_parquet.py | py | 11.1 |
| scripts/load\_historical\_data.py | py | 19.0 |
| scripts/load\_historical\_data\_new.py | py | 10.9 |
| scripts/ml/diagnose\_model.py | py | 2.8 |
| scripts/ml/diagnose\_registry.py | py | 0.2 |
| scripts/remap\_timestamps.py | py | 11.1 |
| scripts/retrain\_model.py | py | 4.2 |
| scripts/run\_dashboard.py | py | 0.7 |
| scripts/simple\_verify.py | py | 2.2 |
| scripts/split\_dataset.py | py | 7.6 |
| scripts/train\_model.py | py | 7.9 |
| scripts/validate\_data\_quality.py | py | 5.5 |
| scripts/verify\_influxDb.py | py | 5.4 |
| scripts/verify\_minio\_storage.py | py | 2.1 |
| src/\_\_init\_\_.py | py | 0.0 |
| src/app/\_\_init\_\_.py | py | 0.0 |
| src/app/api/\_\_init\_\_.py | py | 0.0 |
| src/app/api/main.py | py | 2.4 |
| src/app/api/routes/\_\_init\_\_.py | py | 0.0 |
| src/app/api/routes/analytics.py | py | 4.2 |

## .env.example

# SIEIS Environment Configuration  
# Copy this file to .env and update values as needed  
  
# ============================================================================  
# Kafka Configuration  
# ============================================================================  
KAFKA\_BROKER=redpanda:9092  
KAFKA\_TOPIC=sensor\_readings  
  
# ============================================================================  
# InfluxDB 3.x Configuration (Real-time Hot Data, 30-day retention)  
# ============================================================================  
INFLUX\_URL=http://influxdb3:8181  
INFLUX\_TOKEN=my-super-secret-token  
INFLUX\_DATABASE=sensor\_data  
  
# Note: InfluxDB 3.x uses DATABASE instead of ORG/BUCKET (v2.x concepts removed)  
# Data is automatically retained for 30 days (configured in docker-compose.yml)  
  
# ============================================================================  
# MinIO Configuration (Historical Cold Data, Parquet Archive)  
# ============================================================================  
MINIO\_ENDPOINT=minio:9000  
MINIO\_ACCESS\_KEY=minioadmin  
MINIO\_SECRET\_KEY=minioadmin123  
MINIO\_BUCKET=sieis-archive  
MINIO\_SECURE=false  
  
# Note: For production, change credentials and set MINIO\_SECURE=true  
  
# ============================================================================  
# Simulator Configuration  
# ============================================================================  
SPEED\_FACTOR=100  
DATA\_PATH=/app/data/raw/data.txt  
MOTE\_LOCS\_PATH=/app/data/raw/mote\_locs.txt  
  
# SPEED\_FACTOR controls time compression:  
# 100 = 100x faster (1 hour of data replays in 36 seconds)  
# 1 = real-time (1:1 ratio)  
# 1000 = 1000x faster (very fast for testing)  
  
# ============================================================================  
# Container vs Host Mode  
# ============================================================================  
# When running in Docker containers, services use internal DNS names (above)  
# When running on host (python -m src.app...), use localhost:  
# KAFKA\_BROKER=localhost:9092  
# INFLUX\_URL=http://localhost:8181  
# MINIO\_ENDPOINT=localhost:9000

## Dockerfile.api

FROM python:3.11-slim  
  
WORKDIR /app  
  
COPY requirements.txt .  
RUN pip install --no-cache-dir -r requirements.txt  
  
COPY src/ ./src/  
COPY .env.example .env  
  
# Create models directory  
RUN mkdir -p src/app/ml/models  
  
CMD ["python", "-m", "src.app.api\_server"]

## Dockerfile.consumer

FROM python:3.11-slim  
  
WORKDIR /app  
  
# Install curl for healthchecks  
RUN apt-get update && apt-get install -y curl && rm -rf /var/lib/apt/lists/\*  
  
# Copy requirements first for better layer caching  
COPY requirements.txt .  
  
# Install dependencies  
RUN pip install --no-cache-dir -r requirements.txt  
  
# Copy source code  
COPY src/ ./src/  
  
# Set Python path  
ENV PYTHONUNBUFFERED=1  
  
# Run consumer  
CMD ["python", "-m", "src.app.consumer.main"]

## Dockerfile.dashboard

FROM python:3.11-slim  
  
WORKDIR /app  
  
COPY requirements.txt .  
RUN pip install --no-cache-dir -r requirements.txt  
  
COPY src/ ./src/  
COPY data/ ./data/  
COPY .env.example .env  
  
CMD ["streamlit", "run", "src/app/dashboard/app.py", "--server.port=8501", "--server.address=0.0.0.0", "--browser.gatherUsageStats=false"]

## Dockerfile.scheduler

# ── SIEIS Scheduler Container ─────────────────────────────────────────────────  
# Runs APScheduler with two daily cron jobs:  
# Job A 00:00 UTC — remap incremental timestamps + restart simulator  
# Job B 02:00 UTC — retrain anomaly model + hot-reload FastAPI  
#  
# Requires /var/run/docker.sock mounted (to restart sieis-simulator).  
# ─────────────────────────────────────────────────────────────────────────────  
  
FROM python:3.11-slim  
  
WORKDIR /app  
  
# Install system deps (curl for healthchecks)  
RUN apt-get update && apt-get install -y --no-install-recommends \  
 curl \  
 && rm -rf /var/lib/apt/lists/\*  
  
# Copy and install Python dependencies  
COPY requirements.txt .  
RUN pip install --no-cache-dir -r requirements.txt  
  
# Copy full source so scheduler can import src.app.\* and scripts.\*  
COPY src/ ./src/  
COPY scripts/ ./scripts/  
  
# PYTHONPATH includes /app so both 'src.\*' and 'scripts.\*' resolve correctly  
ENV PYTHONPATH=/app  
  
# ── Runtime defaults (override via docker-compose environment) ────────────────  
ENV SCHEDULER\_TIMEZONE=UTC  
ENV JOB\_A\_HOUR=0  
ENV JOB\_A\_MINUTE=0  
ENV JOB\_B\_HOUR=2  
ENV JOB\_B\_MINUTE=0  
ENV RUN\_JOBS\_ON\_START=false  
ENV SIMULATOR\_CONTAINER=sieis-simulator  
ENV API\_RELOAD\_URL=http://sieis-api:8000/api/v1/ml/model/reload  
ENV INCR\_DATA\_PATH=/app/data/processed/incremental\_data.txt  
  
CMD ["python", "-m", "src.app.scheduler.main"]

## Dockerfile.simulator

FROM python:3.11-slim  
  
WORKDIR /app  
  
# Copy requirements first for better layer caching  
COPY requirements.txt .  
  
# Install dependencies  
RUN pip install --no-cache-dir -r requirements.txt  
  
# Copy source code  
COPY src/ ./src/  
  
# Note: data files are mounted as volumes at runtime  
  
# Set Python path  
ENV PYTHONUNBUFFERED=1  
  
# Run simulator  
CMD ["python", "-m", "src.app.simulator.main"]

## Documentation/QUICKSTART.md

﻿# SIEIS Quick Start  
  
Run the full SIEIS stack (Kafka + Consumer + InfluxDB + MinIO + API + Dashboard + Scheduler) in about 10 minutes.  
  
## 1. Prerequisites  
  
- Docker Desktop running  
- Python 3.11+ (optional, for utility scripts)  
- Git  
  
## 2. Required Data Files  
  
Confirm these files exist:  
  
- `data/raw/mote\_locs.txt`  
- `data/processed/incremental\_data.txt`  
- `data/processed/historical\_data.txt`  
  
If missing, regenerate with project scripts under `data/realtime\_mapping/` and `scripts/`.  
  
## 3. Start the Full Stack  
  
From project root:  
  
```powershell  
docker-compose up --build -d  
```  
  
Check containers:  
  
```powershell  
docker ps --format "table {{.Names}}`t{{.Status}}`t{{.Ports}}"  
```  
  
Expected key containers:  
  
- `sieis-redpanda`  
- `sieis-console`  
- `sieis-influxdb3`  
- `sieis-minio`  
- `sieis-minio-init`  
- `sieis-simulator`  
- `sieis-consumer`  
- `sieis-api`  
- `sieis-dashboard`  
- `sieis-scheduler`  
  
## 4. Verify Services Manually  
  
### 4.1 Core health checks  
  
```powershell  
docker exec sieis-redpanda rpk cluster info  
curl http://localhost:8086/health  
curl http://localhost:9000/minio/health/live  
curl http://localhost:8000/api/v1/health  
```  
  
### 4.2 Web consoles  
  
- Redpanda Console: `http://localhost:8080`  
- InfluxDB UI: `http://localhost:8086`  
- MinIO Console: `http://localhost:9001`  
- Dashboard: `http://localhost:8501`  
- API docs: `http://localhost:8000/docs`  
  
### 4.3 Login credentials  
  
- InfluxDB  
 - Username: `admin`  
 - Password: `password123`  
 - Org: `sieis`  
 - Bucket: `sensor\_data`  
 - Token: `my-super-secret-token`  
- MinIO  
 - Username: `minioadmin`  
 - Password: `minioadmin123`  
 - Bucket: `sieis-archive`  
  
## 5. Verify Streaming and Storage  
  
Consume sample Kafka messages:  
  
```powershell  
docker exec sieis-redpanda rpk topic consume sensor\_readings --num 5  
```  
  
Optional validation scripts:  
  
```powershell  
python scripts/verify\_influxDb.py  
python scripts/verify\_minio\_storage.py  
```  
  
## 6. ML Quick Check (Optional)  
  
Train anomaly model manually:  
  
```powershell  
python scripts/train\_model.py --source minio  
```  
  
Confirm model is loaded:  
  
```powershell  
curl http://localhost:8000/api/v1/ml/model/info  
```  
  
## 7. Scheduler Quick Check (Optional)  
  
Run scheduler jobs immediately for smoke testing:  
  
```powershell  
docker compose down scheduler  
RUN\_JOBS\_ON\_START=true docker compose up scheduler  
```  
  
Default schedule (UTC):  
  
- Job A `00:00`: restart simulator  
- Job B `02:00`: retrain model and reload API model  
  
## 8. Stop or Reset  
  
Stop all services:  
  
```powershell  
docker-compose down  
```  
  
Stop and delete volumes (destructive reset):  
  
```powershell  
docker-compose down -v  
```  
  
## 9. Troubleshooting  
  
- No dashboard data:  
 - `docker logs sieis-consumer`  
 - `docker logs sieis-simulator`  
- API health degraded:  
 - confirm InfluxDB reachable on `8086`  
- MinIO empty:  
 - check `sieis-minio-init` logs and bucket `sieis-archive`  
- Scheduler not acting:  
 - `docker logs sieis-scheduler --tail 200`

## README.md

# SIEIS: Smart Indoor Environmental Intelligence System  
  
## Abstract  
The Smart Indoor Environmental Intelligence System (SIEIS) is a distributed data engineering and analytics platform for streaming environmental telemetry. The project integrates event-driven ingestion, dual-path persistence, API-based serving, dashboard-based observability, and scheduled model lifecycle operations. The objective is to support both low-latency operational monitoring and long-term analytical/ML workflows using a unified architecture.  
  
## 1. System Architecture  
  
### 1.1 Architectural Pattern  
SIEIS follows a dual-write architecture:  
- Hot path for near real-time monitoring and API queries (InfluxDB).  
- Cold path for durable, partitioned, analytical storage (MinIO Parquet).  
  
### 1.2 End-to-End Data Flow  
```text  
Processed Sensor File (incremental\_data.txt)  
 -> Simulator (threaded per mote)  
 -> Redpanda/Kafka topic: sensor\_readings  
 -> Consumer (batch polling + transformation)  
 -> InfluxDB (hot time-series store)  
 -> MinIO (cold Parquet archive)  
  
Serving Layer:  
- FastAPI queries InfluxDB and serves ML inference endpoints  
- Streamlit dashboard consumes InfluxDB/MinIO/API outputs  
  
Automation Layer:  
- APScheduler service restarts simulator daily and retrains/reloads anomaly model  
```  
  
### 1.3 Runtime Topology (Docker Compose)  
```mermaid  
flowchart LR  
 A[Simulator] --> B[Redpanda/Kafka\nsensor\_readings]  
 B --> C[Consumer]  
 C --> D[InfluxDB\nHot Storage]  
 C --> E[MinIO\nCold Storage]  
 D --> F[FastAPI]  
 E --> F  
 D --> G[Streamlit Dashboard]  
 E --> G  
 F --> G  
 H[Scheduler] --> A  
 H --> F  
```  
  
### 1.4 Architecture Diagram  
  
![SIEIS Architecture](Documentation/sieis-system-architecture.png)  
  
## 2. Services and Port Addresses (Manual Verification)  
  
The following table documents all externally exposed ports from the current `docker-compose.yml`.  
  
| Service | Container | Host Port(s) | Internal Address | Manual Verification |  
|---|---|---|---|---|  
| Redpanda (Kafka broker) | `sieis-redpanda` | `19092`, `9092` | `redpanda:9092` | `docker exec sieis-redpanda rpk cluster info` |  
| Redpanda Console | `sieis-console` | `8080` | `redpanda-console:8080` | Open `http://localhost:8080` |  
| InfluxDB | `sieis-influxdb3` | `8086` | `influxdb3:8086` | Open `http://localhost:8086/health` |  
| MinIO API | `sieis-minio` | `9000` | `minio:9000` | Open `http://localhost:9000/minio/health/live` |  
| MinIO Console | `sieis-minio` | `9001` | `minio:9001` | Open `http://localhost:9001` |  
| FastAPI | `sieis-api` | `8000` | `sieis-api:8000` | Open `http://localhost:8000/api/v1/health` |  
| Streamlit Dashboard | `sieis-dashboard` | `8501` | `sieis-dashboard:8501` | Open `http://localhost:8501` |  
| Scheduler | `sieis-scheduler` | none (no host bind) | internal only | `docker logs sieis-scheduler` |  
  
Important note:  
- Host-side Kafka clients should use `localhost:19092`.  
- Inter-container Kafka traffic uses `redpanda:9092`.  
  
### 2.1 Console Credentials and Login Details  
  
Default local development credentials from the current compose configuration:  
  
| Service | Login URL | Username | Password | Additional Details |  
|---|---|---|---|---|  
| Redpanda Console | `http://localhost:8080` | Not required | Not required | Kafka UI only; no auth in local setup |  
| InfluxDB UI | `http://localhost:8086` | `admin` | `password123` | Org: `sieis`, Bucket: `sensor\_data`, Token: `my-super-secret-token` |  
| MinIO Console | `http://localhost:9001` | `minioadmin` | `minioadmin123` | API endpoint: `http://localhost:9000`, Bucket: `sieis-archive` |  
| FastAPI Docs | `http://localhost:8000/docs` | Not required | Not required | Health endpoint: `http://localhost:8000/api/v1/health` |  
  
Security note:  
- These credentials are intended for local academic/development use only.  
- Rotate and externalize secrets before any public or production deployment.  
  
## 3. Local Prerequisites  
  
### 3.1 Platform Requirements  
- Operating System: Windows 10/11, Linux, or macOS  
- Docker Desktop (or Docker Engine + Compose plugin)  
- Python 3.11+  
- Git  
  
### 3.2 Python Dependencies  
  
Install all Python packages from:  
- `requirements.txt`  
  
### 3.3 Required Data Files  
  
The following files should exist before pipeline execution:  
- `data/raw/mote\_locs.txt`  
- `data/processed/incremental\_data.txt` (simulator input)  
- `data/processed/historical\_data.txt` (historical loading and ML utility workflows)  
  
If processed files are absent or stale, regenerate using scripts in:  
- `data/realtime\_mapping/`  
- `scripts/`  
  
## 4. Procedure: Run the Project Locally  
  
### Step 1: Clone and enter the repository  
  
```powershell  
git clone <repository-url>  
cd SIEIS  
```  
  
### Step 2: (Optional but recommended) Create Python virtual environment  
  
```powershell  
python -m venv venv  
.\venv\Scripts\Activate.ps1  
pip install -r requirements.txt  
```  
  
### Step 3: Start full system with Docker Compose  
  
```powershell  
docker-compose up --build -d  
```  
  
### Step 4: Validate container startup  
  
```powershell  
docker ps --format "table {{.Names}}\t{{.Status}}\t{{.Ports}}"  
```  
  
Expected containers include:  
- `sieis-redpanda`  
- `sieis-console`  
- `sieis-influxdb3`  
- `sieis-minio`  
- `sieis-minio-init`  
- `sieis-simulator`  
- `sieis-consumer`  
- `sieis-api`  
- `sieis-dashboard`  
- `sieis-scheduler`  
  
### Step 5: Manual service verification  
  
1. Verify Kafka broker  
  
```powershell  
docker exec sieis-redpanda rpk cluster info  
```  
  
2. Verify InfluxDB  
  
```powershell  
curl http://localhost:8086/health  
```  
  
3. Verify MinIO  
  
```powershell  
curl http://localhost:9000/minio/health/live  
```  
  
4. Verify API  
  
```powershell  
curl http://localhost:8000/api/v1/health  
```  
  
5. Verify message flow  
  
```powershell  
docker exec sieis-redpanda rpk topic consume sensor\_readings --num 5  
```  
  
6. Open web interfaces  
  
- Redpanda Console: `http://localhost:8080`  
- InfluxDB UI: `http://localhost:8086`  
- MinIO Console: `http://localhost:9001`  
- Dashboard: `http://localhost:8501`  
  
### Step 6: Shut down environment  
  
```powershell  
docker-compose down  
```  
  
Remove volumes (destructive) when complete reset is required:  
  
```powershell  
docker-compose down -v  
```  
  
## 5. Local Development Execution (Without Full Compose)  
  
For targeted debugging, services can be run directly from Python entry points:  
  
```powershell  
python -m src.app.simulator.main  
python -m src.app.consumer.main  
python -m src.app.api\_server  
python scripts/run\_dashboard.py  
```  
  
Use host-compatible environment values in `.env` (for example, `localhost` endpoints) when running services outside containers.  
  
## 6. Project Folder Structure  
  
```text  
SIEIS/  
|-- docker-compose.yml  
|-- requirements.txt  
|-- README.md  
|-- QUICKSTART.md  
|-- .env.example  
|-- data/  
| |-- raw/  
| | `-- mote\_locs.txt  
| |-- processed/  
| | |-- historical\_data.txt  
| | |-- incremental\_data.txt  
| | `-- realtime\_data.txt  
| `-- realtime\_mapping/  
| |-- transform\_to\_realtime.py  
| |-- preview\_mapping.py  
| `-- validate\_output.py  
|-- src/  
| `-- app/  
| |-- config.py  
| |-- api\_server.py  
| |-- api/  
| | |-- main.py  
| | |-- schemas.py  
| | `-- routes/  
| | |-- sensors.py  
| | |-- analytics.py  
| | `-- ml.py  
| |-- simulator/  
| | |-- main.py  
| | |-- orchestrator.py  
| | |-- emitter.py  
| | |-- producer.py  
| | `-- data\_loader.py  
| |-- consumer/  
| | |-- main.py  
| | |-- kafka\_consumer.py  
| | |-- influx\_writer.py  
| | `-- parquet\_writer.py  
| |-- dashboard/  
| | |-- app.py  
| | `-- pages/  
| | |-- 1\_Realtime\_Monitor.py  
| | |-- 2\_Historical\_Analysis.py  
| | `-- 3\_Anomaly\_Detection.py  
| |-- ml/  
| | |-- detector.py  
| | |-- models/  
| | | `-- model\_registry.json  
| | `-- preprocessing/  
| | `-- data\_prep.py  
| `-- scheduler/  
| |-- main.py  
| `-- jobs.py  
|-- scripts/  
| |-- load\_historical\_data.py  
| |-- split\_dataset.py  
| |-- remap\_timestamps.py  
| |-- train\_model.py  
| |-- retrain\_model.py  
| `-- verify\_\*.py  
|-- tests/  
| |-- test\_e2e\_pipeline.py  
| |-- test\_full\_pipeline.py  
| |-- test\_data\_loader.py  
| `-- test\_container\_\*.py  
`-- Documentation/  
 |-- ARCHITECTURE.md  
 |-- DEPLOYMENT.md  
 |-- ML\_MODELS.md  
 `-- PROJECT\_CONTEXT.md  
```  
  
Structure note:  
- `src/app/` contains runtime services and application logic.  
- `scripts/` contains operational utilities (data prep, loading, verification, model workflows).  
- `data/processed/` stores the categorized datasets used to emulate archival plus incremental IoT flow.  
  
## 7. Troubleshooting Quick Reference  
  
- If API is healthy but dashboard is empty, verify Kafka consumption and Influx writes via `docker logs sieis-consumer`.  
- If simulator produces no current records, regenerate mapped data in `data/realtime\_mapping` and restart `sieis-simulator`.  
- If MinIO appears empty, verify bucket initialization from `sieis-minio-init` logs.  
- If model endpoints use fallback mode, train/retrain a model and call `POST /api/v1/ml/model/reload`.  
  
## 8. Data Source and Temporal Categorization for Real-Time IoT Emulation  
  
### 8.1 Source Dataset  
  
SIEIS uses the Intel Lab sensor dataset (historical indoor environmental telemetry), where each record includes:  
- date and time  
- epoch/sample index  
- mote identifier  
- temperature, humidity, light, and voltage  
  
The original dataset is historical (early 2000s), so it does not naturally behave as a present-day live stream.  
  
### 8.2 Preprocessing and Time Remapping  
  
To make legacy telemetry operationally useful for current-time demonstrations, the pipeline adds a derived field:  
- `updated\_timestamp`: a remapped timestamp aligned to the present calendar window  
  
This preserves the original intra-series behavior (ordering and temporal spacing) while shifting records into an interpretable modern timeline.  
  
### 8.3 Historical vs Incremental Categorization  
  
The project organizes processed data into three artifacts under `data/processed/`:  
  
1. `realtime\_data.txt`  
 - Full remapped dataset (complete timeline representation).  
  
2. `historical\_data.txt`  
 - Archive-oriented partition (typically the older 80% block after chronological split).  
 - Used for backfill, long-horizon analysis, and model training workflows.  
 - Loaded through historical loaders into MinIO Parquet (and optionally InfluxDB as needed).  
  
3. `incremental\_data.txt`  
 - Stream-oriented partition (typically the newer 20% block).  
 - Used by the simulator as the active feed for Kafka publication.  
 - Represents the "arriving" portion of data to mimic ongoing sensor production.  
  
### 8.4 Why This Mimics a Real IoT Scenario  
  
This design reproduces the operational structure of production IoT systems:  
- historical corpus retained in a cold analytical tier (MinIO/Parquet),  
- incremental events continuously emitted through a message bus (Kafka/Redpanda),  
- low-latency monitoring served from hot time-series storage (InfluxDB),  
- periodic model retraining on accumulated historical data.  
  
Consequently, SIEIS can emulate:  
- streaming ingestion dynamics,  
- online dashboard/API consumption,  
- offline analytical and ML lifecycle tasks,  
- and the natural separation between "already observed" and "newly arriving" telemetry.  
  
## 9. ML Training, Retraining, and Scheduler Automation  
  
### 9.1 ML Component Overview  
  
SIEIS uses an Isolation Forest anomaly detector implemented in:  
- `src/app/ml/detector.py`  
- `src/app/ml/preprocessing/data\_prep.py`  
  
Model artifacts are stored in:  
- `src/app/ml/models/anomaly\_detector\_\*.pkl`  
  
The active model pointer is tracked in:  
- `src/app/ml/models/model\_registry.json`  
  
FastAPI serves inference and model-management endpoints:  
- `POST /api/v1/ml/predict/anomaly`  
- `GET /api/v1/ml/model/info`  
- `POST /api/v1/ml/model/reload`  
  
### 9.2 Initial Model Training (Manual)  
  
Run this after historical data is available (local file or MinIO Parquet):  
  
```powershell  
python scripts/train\_model.py --source minio  
```  
  
Useful variants:  
  
```powershell  
python scripts/train\_model.py --source local --max-rows 200000  
python scripts/train\_model.py --source minio --contamination 0.03  
python scripts/train\_model.py --source minio --tag baseline\_v1  
```  
  
What the script does:  
1. Loads training data (`minio` or `local` source)  
2. Prepares features (`temperature`, `humidity`, `light`, `voltage`, `hour`, `day\_of\_week`)  
3. Trains Isolation Forest  
4. Saves model artifact and updates `model\_registry.json`  
5. Attempts API model reload and sends a test prediction  
  
### 9.3 Incremental Retraining (Manual)  
  
Use retraining when new data arrives and you want to refresh model behavior:  
  
```powershell  
python scripts/retrain\_model.py --source minio --days 30  
```  
  
Alternative source:  
  
```powershell  
python scripts/retrain\_model.py --source influxdb --days 7  
```  
  
After retraining, reload the API model if not automatically reloaded:  
  
```powershell  
curl -X POST http://localhost:8000/api/v1/ml/model/reload  
```  
  
### 9.4 Scheduler-Based Daily Automation  
  
The `scheduler` container (`src/app/scheduler/main.py`) runs two UTC cron jobs:  
  
- Job A (`00:00 UTC`): `remap\_and\_restart`  
 - Current implementation restarts `sieis-simulator`.  
 - This ensures the simulator process starts a fresh emission cycle.  
  
- Job B (`02:00 UTC`): `retrain\_and\_reload`  
 - Loads recent data from MinIO Parquet.  
 - Trains a new Isolation Forest model.  
 - Saves a timestamped model with `scheduled` tag.  
 - Calls API reload endpoint so inference uses the latest model without container restart.  
  
Immediate smoke test (run both jobs on startup):  
  
```powershell  
docker compose up -d scheduler  
docker compose down scheduler  
RUN\_JOBS\_ON\_START=true docker compose up scheduler  
```  
  
Scheduler runtime configuration is controlled by environment variables in `docker-compose.yml`, including:  
- `SCHEDULER\_TIMEZONE`  
- `JOB\_A\_HOUR`, `JOB\_A\_MINUTE`  
- `JOB\_B\_HOUR`, `JOB\_B\_MINUTE`  
- `RUN\_JOBS\_ON\_START`  
  
### 9.5 Verification After Training/Retraining  
  
1. Confirm API sees the model:  
  
```powershell  
curl http://localhost:8000/api/v1/ml/model/info  
```  
  
2. Confirm health includes model-loaded state:  
  
```powershell  
curl http://localhost:8000/api/v1/health  
```  
  
3. Confirm scheduler execution logs:  
  
```powershell  
docker logs sieis-scheduler --tail 200  
```  
  
4. Confirm new model files are created:  
  
```powershell  
Get-ChildItem src\\app\\ml\\models\\anomaly\_detector\_\*.pkl | Sort-Object LastWriteTime -Descending | Select-Object -First 5  
```

data/.checkpoint\_historical.json

{  
 "last\_line": 0,  
 "timestamp": "2026-02-25T11:44:52.529371",  
 "stats": {  
 "total\_read": 0,  
 "influx\_written": 0,  
 "minio\_written": 0,  
 "skipped": 0,  
 "errors": 0  
 },  
 "note": "Reset by clear\_storage.py"  
}

## data/raw/mote\_locs.txt

1 21.5 23  
2 24.5 20  
3 19.5 19  
4 22.5 15  
5 24.5 12  
6 19.5 12  
7 22.5 8  
8 24.5 4  
9 21.5 2  
10 19.5 5  
11 16.5 3  
12 13.5 1  
13 12.5 5  
14 8.5 6  
15 5.5 3  
16 1.5 2  
17 1.5 8  
18 5.5 10  
19 3.5 13  
20 0.5 17  
21 4.5 18  
22 1.5 23  
23 6 24  
24 1.5 30  
25 4.5 30  
26 7.5 31  
27 8.5 26  
28 10.5 31  
29 12.5 26  
30 13.5 31  
31 15.5 28  
32 17.5 31  
33 19.5 26  
34 21.5 30  
35 24.5 27  
36 26.5 31  
37 27.5 26  
38 30.5 31  
39 30.5 26  
40 33.5 28  
41 36.5 30  
42 39.5 30  
43 35.5 24  
44 40.5 22  
45 37.5 19  
46 34.5 16  
47 39.5 14  
48 35.5 10  
49 39.5 6  
50 38.5 1  
51 35.5 4  
52 31.5 6  
53 28.5 5  
54 26.5 2

## data/realtime\_mapping/README.md

# Real-Time Data Mapping Scripts  
  
This folder contains scripts to transform historical sensor data (2004) into real-time relevant timestamps (2026).  
  
## Strategy  
  
Maps the date range proportionally with an 80% anchor point:  
- The date at 80% of the original range → Today's date  
- All other dates map proportionally backwards  
- Future dates are filtered out  
  
\*\*Example:\*\*  
- Original: 2004-02-28 to 2004-05-01 (63 days)  
- 80% point: 2004-04-18 → 2026-02-16 (today)  
- 2004-02-28 → 2026-01-28 (19 days ago)  
- 2004-04-17 → 2026-02-15 (yesterday)  
  
## Scripts  
  
### 1. `preview\_mapping.py`  
Preview the date mapping before transformation.  
  
```bash  
python data/realtime\_mapping/preview\_mapping.py  
```  
  
\*\*Output:\*\* Shows how each original date will map to new dates.  
  
### 2. `transform\_to\_realtime.py`  
Main transformation script that creates the real-time data file.  
  
```bash  
python data/realtime\_mapping/transform\_to\_realtime.py  
```  
  
\*\*Input:\*\* `data/data.csv` (original)   
\*\*Output:\*\*   
- `data/data\_realtime.csv` (CSV format with headers)  
- `data/processed/realtime\_data.txt` (Space-delimited format, no headers)  
  
### 3. `validate\_output.py`  
Validates the transformed data file.  
  
```bash  
python data/realtime\_mapping/validate\_output.py  
```  
  
\*\*Checks:\*\*  
- Date distribution  
- Timestamp consistency  
- No future dates  
- Record counts  
  
## Usage Workflow  
  
```bash  
# Step 1: Preview the mapping (optional)  
python data/realtime\_mapping/preview\_mapping.py  
  
# Step 2: Transform the data  
python data/realtime\_mapping/transform\_to\_realtime.py  
  
# Step 3: Validate output (optional)  
python data/realtime\_mapping/validate\_output.py  
  
# Step 4: Update docker-compose.yml  
# Change simulator volume from:  
# - ./data/data.csv:/data/data.csv:ro  
# To:  
# - ./data/data\_realtime.csv:/data/data.csv:ro  
  
# Step 5: Restart containers  
docker-compose restart simulator consumer  
  
# Step 6: Run tests  
python tests/test\_full\_pipeline.py  
```  
  
## Output Formats  
  
### CSV Format (`data/data\_realtime.csv`)  
Standard CSV with headers:  
```csv  
date,time,epoch,moteid,temperature,humidity,light,voltage,updated\_timestamp  
2004-02-28,00:59:16.02785,3,1,19.9884,37.0933,45.08,2.69964,2026-01-17T00:59:16.027850  
```  
  
\*\*Columns:\*\*  
- `date`: Original date from 2004  
- `time`: Original time of day  
- `epoch`: Epoch/batch number  
- `moteid`: Sensor/mote identifier  
- `temperature`: Temperature reading (°C)  
- `humidity`: Humidity reading (%)  
- `light`: Light reading (lux)  
- `voltage`: Battery voltage (V)  
- `updated\_timestamp`: \*\*New\*\* - Mapped timestamp in 2026 (ISO 8601 format)  
  
### TXT Format (`data/processed/realtime\_data.txt`)  
Space-delimited, no headers (for legacy systems):  
```  
2004-02-28 00:59:16.02785 3 1 19.9884 37.0933 45.08 2.69964 2026-01-17T00:59:16.027850  
```  
  
\*\*Column order:\*\*  
1. date (original)  
2. time (original)  
3. epoch  
4. moteid  
5. temperature  
6. humidity  
7. light  
8. voltage  
9. updated\_timestamp (mapped to 2026)  
  
## Transformation Details  
  
### Date Mapping Algorithm  
  
1. \*\*Analyze original dataset:\*\*  
 - Find min date, max date, total span  
 - Calculate 80% point (day 50 of 63 = 2004-04-18)  
  
2. \*\*Create proportional mapping:\*\*  
 - Anchor: Date at 80% → Today  
 - All dates map relative to this anchor  
 - Preserves time-of-day from original timestamps  
  
3. \*\*Filter future dates:\*\*  
 - Any timestamp > now() is excluded  
 - Prevents InfluxDB rejection (can't write future data)  
  
### Example Transformation  
  
```  
Original Range: 2004-02-28 to 2004-05-01 (63 days)  
Current Date: 2026-02-16  
  
Mapping:  
├─ 2004-02-28 → 2026-01-28 (19 days ago) ← Oldest  
├─ 2004-03-15 → 2026-02-02 (14 days ago)  
├─ 2004-04-17 → 2026-02-15 (1 day ago)  
├─ 2004-04-18 → 2026-02-16 (TODAY) ⭐ 80% anchor  
├─ 2004-04-19 → 2026-02-17 (FUTURE - filtered out)  
└─ 2004-05-01 → 2026-03-01 (FUTURE - filtered out) ← Newest  
```  
  
## Statistics from Last Run  
  
```  
📊 Original Dataset:  
 Records: 2,313,682  
 Date Range: 2004-02-28 to 2004-05-01  
 Unique Dates: 63  
 80% Point: 2004-04-18  
  
✅ Transformation Results:  
 Mapped Records: 1,823,589 (78.8%)  
 Filtered (future): 490,093 (21.2%)  
   
📈 Distribution:  
 Today: 856,234 records (47.0%)  
 Historical (1-30 days ago): 967,355 records (53.0%)  
```  
  
## File Locations  
  
```  
data/  
├── data.csv # Original (untouched)  
├── data\_realtime.csv # Transformed CSV  
└── processed/  
 └── realtime\_data.txt # Transformed TXT (space-delimited)  
  
data/realtime\_mapping/  
├── README.md # This file  
├── preview\_mapping.py # Preview script  
├── transform\_to\_realtime.py # Main transformation  
└── validate\_output.py # Validation script  
```  
  
## Integration with SIEIS Pipeline  
  
### Before Transformation  
```  
CSV (2004 dates) → Simulator → Kafka → Consumer → InfluxDB ❌ (rejected)  
 → MinIO ✅ (works)  
```  
  
\*\*Issue:\*\* InfluxDB rejects data outside retention window (30 days default)  
  
### After Transformation  
```  
CSV (2026 dates) → Simulator → Kafka → Consumer → InfluxDB ✅ (accepted)  
 → MinIO ✅ (works)  
```  
  
\*\*Result:\*\* Both hot path (InfluxDB) and cold path (MinIO) work correctly  
  
## Notes  
  
- ✅ Preserves time-of-day from original timestamps for realism  
- ✅ Filters out any records that would map to future dates  
- ✅ Safe to re-run multiple times (overwrites output files)  
- ✅ Does not modify original `data/data.csv`  
- ✅ Creates `data/processed/` directory if it doesn't exist  
- ✅ Both CSV and TXT formats generated automatically  
- ⚠️ TXT format has NO headers (by design for legacy compatibility)  
- ⚠️ Re-run transformation when testing on different days (dates shift)  
  
## Troubleshooting  
  
### Problem: "No data in InfluxDB"  
\*\*Solution:\*\* Ensure you're using `data\_realtime.csv` in docker-compose.yml  
  
### Problem: "All data filtered out"  
\*\*Cause:\*\* Running script on a different date than dataset was created   
\*\*Solution:\*\* Re-run `transform\_to\_realtime.py` to regenerate with current date  
  
### Problem: "Future timestamp rejected"  
\*\*Cause:\*\* System clock incorrect or transformation bug   
\*\*Solution:\*\*   
1. Check system date: `date` (Linux/Mac) or `Get-Date` (PowerShell)  
2. Validate output: `python data/realtime\_mapping/validate\_output.py`  
  
### Problem: "CSV has headers but TXT doesn't"  
\*\*Expected:\*\* This is by design. Use CSV for imports, TXT for legacy systems.  
  
## Version History  
  
- \*\*v1.0.0\*\* (2026-02-16): Initial release with 80% proportional mapping  
- \*\*v1.1.0\*\* (2026-02-16): Added TXT format output to `data/processed/`  
  
## Related Documentation  
  
- [SIEIS Architecture](../../Documentation/ARCHITECTURE.md)  
- [Retention Policy Guide](../../Documentation/RETENTION\_POLICY\_GUIDE.md)  
- [Testing Guide](../../tests/README.md)

## data/realtime\_mapping/preview\_mapping.py

"""  
Preview how dates will be mapped without creating the full file.  
Quick way to verify the mapping logic before processing.  
"""  
  
import csv  
from datetime import datetime, timedelta  
from pathlib import Path  
import logging  
  
logging.basicConfig(level=logging.INFO, format='%(message)s')  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def main():  
 # Navigate to project root from data/realtime\_mapping/  
 script\_dir = Path(\_\_file\_\_).parent  
 project\_root = script\_dir.parent.parent  
 input\_file = project\_root / "data" / "data.csv"  
   
 if not input\_file.exists():  
 logger.error(f"❌ File not found: {input\_file}")  
 logger.info(f"\nSearching for data files...")  
   
 # Try alternative locations  
 alt\_locations = [  
 project\_root / "data" / "raw" / "data.txt",  
 project\_root / "data" / "data.txt",  
 ]  
   
 for alt\_file in alt\_locations:  
 if alt\_file.exists():  
 logger.info(f"Found: {alt\_file}")  
 input\_file = alt\_file  
 break  
 else:  
 logger.error(f"\n❌ No data file found. Please ensure data.csv exists in:")  
 logger.error(f" {project\_root / 'data' / 'data.csv'}")  
 return 1  
   
 logger.info("🔍 Previewing Date Mapping")  
 logger.info(f"📂 Input: {input\_file.relative\_to(project\_root)}\n")  
   
 # Read all unique dates  
 dates = []  
 with open(input\_file, 'r') as f:  
 # Check if space-delimited or CSV  
 first\_line = f.readline()  
 f.seek(0)  
   
 if ',' in first\_line:  
 # CSV format  
 reader = csv.DictReader(f)  
 for row in reader:  
 try:  
 ts = datetime.strptime(row['date'], "%Y-%m-%d %H:%M:%S.%f")  
 except (ValueError, KeyError):  
 continue  
 dates.append(ts.date())  
 else:  
 # Space-delimited format: date time mote\_id epoch temp humidity light voltage  
 for line in f:  
 parts = line.strip().split()  
 if len(parts) >= 2:  
 try:  
 timestamp\_str = f"{parts[0]} {parts[1]}"  
 ts = datetime.strptime(timestamp\_str, "%Y-%m-%d %H:%M:%S.%f")  
 dates.append(ts.date())  
 except ValueError:  
 continue  
   
 if not dates:  
 logger.error("❌ No valid dates found in file")  
 return 1  
   
 unique\_dates = sorted(set(dates))  
 min\_date = unique\_dates[0]  
 max\_date = unique\_dates[-1]  
 total\_days = (max\_date - min\_date).days + 1  
   
 # Calculate 80% point  
 days\_to\_80 = int(total\_days \* 0.80)  
 date\_at\_80 = min\_date + timedelta(days=days\_to\_80)  
   
 today = datetime.now().date()  
   
 logger.info(f"📊 Original Dataset:")  
 logger.info(f" Date Range: {min\_date} to {max\_date}")  
 logger.info(f" Total Days: {total\_days}")  
 logger.info(f" Unique Dates: {len(unique\_dates)}")  
 logger.info(f" 80% Point: {date\_at\_80} (day {days\_to\_80})")  
   
 logger.info(f"\n🎯 Mapping Strategy:")  
 logger.info(f" {date\_at\_80} → {today} (TODAY)")  
 logger.info(f" All dates map relative to this anchor")  
   
 logger.info(f"\n📋 Complete Date Mapping:\n")  
 logger.info(f" {'Original Date':<15} → {'New Date':<15} {'Description'}")  
 logger.info(f" {'-'\*15} {'-'\*15} {'-'\*30}")  
   
 # Show all mappings  
 for orig\_date in unique\_dates:  
 days\_offset = (orig\_date - date\_at\_80).days  
 new\_date = today + timedelta(days=days\_offset)  
   
 # Description  
 diff = (new\_date - today).days  
 if diff == 0:  
 desc = "TODAY ⭐"  
 elif diff < 0:  
 desc = f"{abs(diff)} days ago"  
 else:  
 desc = f"{diff} days in FUTURE (filtered)"  
   
 # Highlight special dates  
 marker = ""  
 if orig\_date == min\_date:  
 marker = " ← oldest"  
 elif orig\_date == max\_date:  
 marker = " ← newest"  
 elif orig\_date == date\_at\_80:  
 marker = " ← 80% anchor"  
   
 logger.info(f" {orig\_date} → {new\_date} {desc}{marker}")  
   
 # Count records per date  
 logger.info(f"\n📊 Records per Original Date:")  
 date\_counts = {}  
 for d in dates:  
 date\_counts[d] = date\_counts.get(d, 0) + 1  
   
 for date in sorted(date\_counts.keys())[:10]:  
 count = date\_counts[date]  
 logger.info(f" {date}: {count:,} records")  
   
 if len(date\_counts) > 10:  
 logger.info(f" ... ({len(date\_counts) - 10} more dates)")  
   
 # Calculate expected distribution  
 future\_count = sum(1 for d in dates if (today + timedelta(days=(d - date\_at\_80).days)) > today)  
 past\_count = sum(1 for d in dates if (today + timedelta(days=(d - date\_at\_80).days)) <= today)  
   
 logger.info(f"\n📈 Expected Output:")  
 logger.info(f" Total records: {len(dates):,}")  
 logger.info(f" Will be kept: {past\_count:,} ({past\_count/len(dates)\*100:.1f}%)")  
 logger.info(f" Will be filtered (future): {future\_count:,} ({future\_count/len(dates)\*100:.1f}%)")  
   
 logger.info(f"\n✅ Ready to transform? Run:")  
 logger.info(f" python data/realtime\_mapping/transform\_to\_realtime.py")  
   
 return 0  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 exit(main())

## data/realtime\_mapping/transform\_to\_realtime.py

"""  
Split raw sensor data into Historical and Incremental datasets with time mapping.  
  
Logic:  
1. Load raw data from data/raw/data.txt  
2. Sort by timestamp (ascending)  
3. Determine 80% split point based on time range  
4. Split data:  
 - Historical: <= 80% date (Mapped so last date = TODAY, rest backwards)  
 - Incremental: > 80% date (Mapped so first date = TOMORROW, rest forwards)  
"""  
  
import logging  
import pandas as pd  
from datetime import datetime, timedelta  
from pathlib import Path  
import sys  
  
# Configure logging  
logging.basicConfig(  
 level=logging.INFO,  
 format='%(asctime)s - %(levelname)s - %(message)s'  
)  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def parse\_raw\_data(file\_path):  
 """  
 Read raw intel lab data.  
 Format is space separated: date time epoch moteid temp humidity light voltage  
 """  
 logger.info(f"📖 Reading raw data from {file\_path}...")  
   
 # Define column names based on Intel Lab dataset format  
 col\_names = ['date', 'time', 'epoch', 'moteid', 'temperature', 'humidity', 'light', 'voltage']  
   
 try:  
 # Read using pandas for efficiency  
 df = pd.read\_csv(  
 file\_path,   
 sep=r'\s+',   
 header=None,   
 names=col\_names,  
 on\_bad\_lines='skip',  
 engine='python' # Python engine is more robust for variable whitespace  
 )  
   
 # Create a single timestamp column for sorting  
 df['original\_ts'] = pd.to\_datetime(  
 df['date'] + ' ' + df['time'],   
 format='%Y-%m-%d %H:%M:%S.%f',   
 errors='coerce'  
 )  
   
 # Drop invalid rows  
 initial\_len = len(df)  
 df = df.dropna(subset=['original\_ts'])  
 if len(df) < initial\_len:  
 logger.warning(f"⚠️ Dropped {initial\_len - len(df)} rows with invalid timestamps")  
   
 # Sort by timestamp  
 logger.info("⚡ Sorting data by timestamp...")  
 df = df.sort\_values('original\_ts')  
   
 return df  
   
 except Exception as e:  
 logger.error(f"❌ Failed to parse data: {e}")  
 raise  
  
  
def calculate\_split\_date(df):  
 """Find the date that represents the 80% mark of the time range."""  
 min\_date = df['original\_ts'].min()  
 max\_date = df['original\_ts'].max()  
   
 total\_duration = max\_date - min\_date  
 split\_offset = total\_duration \* 0.8  
 split\_date = min\_date + split\_offset  
   
 logger.info(f"📅 Date Range: {min\_date} to {max\_date}")  
 logger.info(f"⏱️ Duration: {total\_duration}")  
 logger.info(f"✂️ 80% Split Timestamp: {split\_date}")  
   
 return split\_date  
  
  
def map\_timestamps(df, target\_anchor\_date, is\_historical=True):  
 """  
 Map timestamps to new range.  
   
 Args:  
 df: DataFrame slice  
 target\_anchor\_date: The target date to map the specific anchor point to.  
 is\_historical:   
 If True: Map MAX date in df -> target\_anchor\_date (Today).  
 If False: Map MIN date in df -> target\_anchor\_date (Tomorrow).  
 """  
 if df.empty:  
 return df  
  
 # Calculate offsets  
 if is\_historical:  
 # For historical: Last record = Today (aligned at same time of day as original max)  
 anchor\_original = df['original\_ts'].max()  
 time\_offset = target\_anchor\_date - anchor\_original  
 logger.info(f"Mapping Historical: Max Original {anchor\_original} -> Target {target\_anchor\_date}")  
 else:  
 # For incremental: First record = Tomorrow (Start of day)  
 anchor\_original = df['original\_ts'].min()  
 time\_offset = target\_anchor\_date - anchor\_original  
 logger.info(f"Mapping Incremental: Min Original {anchor\_original} -> Target {target\_anchor\_date}")  
  
 # Apply offset  
 df = df.copy()  
 df['updated\_timestamp'] = df['original\_ts'] + time\_offset  
   
 return df  
  
  
def save\_processed\_file(df, output\_path):  
 """Save the processed DataFrame to CSV/TXT format expected by simulator."""  
 if df.empty:  
 logger.warning(f"⚠️ Skipping empty dataframe save to {output\_path}")  
 return  
  
 logger.info(f"💾 Saving {len(df):,} records to {output\_path}...")  
   
 # NEW LOGIC: Format updated\_timestamp to be ISO format (no spaces) to prevent parse errors downstream  
 # pd.to\_csv default string representation might include spaces.  
 if 'updated\_timestamp' in df.columns:  
 # We need to operate on a copy or modify safely.   
 # Since this function is the last step for these DFs, modifying in place or copy is fine.  
 df = df.copy()  
 df['updated\_timestamp'] = df['updated\_timestamp'].dt.strftime('%Y-%m-%dT%H:%M:%S.%f')  
   
 # Ensure directory exists  
 output\_path.parent.mkdir(parents=True, exist\_ok=True)  
   
 # Columns to save: original columns + updated\_timestamp  
 # Note: Simulator might expect specific column order. Usually it reads columns by name if header/names provided in pd.read\_csv  
 # Original raw data has no header.  
 # Our data\_loader.py reads: 'date', 'time', 'epoch', 'moteid', 'temperature', 'humidity', 'light', 'voltage', 'updated\_timestamp'  
   
 cols\_to\_save = ['date', 'time', 'epoch', 'moteid', 'temperature', 'humidity', 'light', 'voltage', 'updated\_timestamp']  
   
 # Use space separator as per original format, no header, index=False  
 import csv as csv\_module  
 df.to\_csv(  
 output\_path,   
 sep=' ',   
 index=False,   
 columns=cols\_to\_save,   
 header=False,   
 quoting=csv\_module.QUOTE\_NONE,   
 escapechar=' '  
 )  
  
  
def main():  
 script\_dir = Path(\_\_file\_\_).parent  
 project\_root = script\_dir.parent.parent  
   
 # Check possible input file locations  
 possible\_inputs = [  
 project\_root / "data" / "raw" / "data.txt",  
 project\_root / "data" / "data.txt"  
 ]  
   
 raw\_file = None  
 for p in possible\_inputs:  
 if p.exists():  
 raw\_file = p  
 break  
   
 if not raw\_file:  
 logger.error("❌ Raw data file not found in data/raw/data.txt")  
 return 1  
  
 # 1. Load and Sort  
 try:  
 df = parse\_raw\_data(raw\_file)  
 except Exception as e:  
 logger.error(f"Failed to load data: {e}")  
 return 1  
   
 # 2. Determine Split  
 split\_timestamp = calculate\_split\_date(df)  
   
 # 3. Split Dataframes  
 mask\_historical = df['original\_ts'] <= split\_timestamp  
 df\_hist = df[mask\_historical].copy()  
 df\_incr = df[~mask\_historical].copy()  
   
 logger.info(f"📊 Split Stats:")  
 logger.info(f" Historical Records: {len(df\_hist):,} (Max Orig Date: {df\_hist['original\_ts'].max()})")  
 logger.info(f" Incremental Records: {len(df\_incr):,} (Min Orig Date: {df\_incr['original\_ts'].min() if not df\_incr.empty else 'N/A'})")  
  
 # 4. Map Dates  
 now = datetime.now()  
 today = now.replace(hour=0, minute=0, second=0, microsecond=0)  
   
 # Calculate target anchor for Historical (End of Today or Now?)  
 # "80th% percent date is mapped to today" implies the end of the historical range is today.  
 # Let's map it to NOW.  
 target\_hist\_anchor = now  
   
 df\_hist\_mapped = map\_timestamps(df\_hist, target\_hist\_anchor, is\_historical=True)  
   
 # Calculate target anchor for Incremental  
 # User requested: "transmit only current day data from incremental data file"  
 # To facilitate this, we start the incremental data TODAY (now + 1 minute)   
 # instead of tomorrow, so the simulator picks it up immediately.  
 target\_incr\_start = now + timedelta(minutes=1)  
   
 df\_incr\_mapped = map\_timestamps(df\_incr, target\_incr\_start, is\_historical=False)  
  
 # 5. Save Files  
 output\_dir = project\_root / "data" / "processed"  
   
 save\_processed\_file(df\_hist\_mapped, output\_dir / "historical\_data.txt")  
 save\_processed\_file(df\_incr\_mapped, output\_dir / "incremental\_data.txt")  
   
 # 6. Create 'realtime\_data.txt' for simulator backward compatibility  
 # The simulator currently points to data/processed/realtime\_data.txt  
 # We should probably combine them or just use historical?  
 # Request implies splitting, maybe for a staged simulation (load historical, then stream incremental).  
 # For now, I'll save the historical data as 'realtime\_data.txt' too so the current simulator has something relevant to play.  
 # OR better: save the concatenation of both mapped datasets to realtime\_data.txt so the simulator can iterate through all.  
 # Since mapped timestamps are contiguous (Today -> Tomorrow...), let's save the Combined set.  
   
 logger.info("🔗 Creating combined realtime\_data.txt for simulator compatibility...")  
 df\_combined = pd.concat([df\_hist\_mapped, df\_incr\_mapped])  
 save\_processed\_file(df\_combined, output\_dir / "realtime\_data.txt")  
   
 logger.info("✅ Data transformation complete.")  
 logger.info(f" Output 1: {output\_dir / 'historical\_data.txt'}")  
 logger.info(f" Output 2: {output\_dir / 'incremental\_data.txt'}")  
 logger.info(f" Output 3: {output\_dir / 'realtime\_data.txt'} (Combined)")  
 return 0  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 sys.exit(main())

## data/realtime\_mapping/validate\_output.py

"""  
Validate the transformed real-time data file.  
Checks for data integrity, distribution, and timestamp consistency.  
"""  
  
import csv  
from datetime import datetime  
from pathlib import Path  
from collections import defaultdict  
import logging  
  
logging.basicConfig(level=logging.INFO, format='%(message)s')  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def validate\_output\_file(output\_file):  
 """Perform comprehensive validation of the transformed data."""  
   
 logger.info("🔍 Validating Transformed Data File")  
 logger.info(f"📂 File: {output\_file}\n")  
   
 if not output\_file.exists():  
 logger.error(f"❌ File not found: {output\_file}")  
 logger.info("\nRun transformation first:")  
 logger.info(" python data/realtime\_mapping/transform\_to\_realtime.py")  
 return False  
   
 # Validation metrics  
 total\_records = 0  
 today\_count = 0  
 historical\_count = 0  
 future\_count = 0  
   
 mote\_ids = set()  
 date\_distribution = defaultdict(int)  
 fields\_summary = defaultdict(lambda: {'count': 0, 'sum': 0, 'min': float('inf'), 'max': float('-inf')})  
   
 sample\_records = []  
 errors = []  
   
 today = datetime.now().date()  
 now = datetime.now()  
   
 # Read and analyze  
 logger.info("📊 Analyzing data...")  
   
 with open(output\_file, 'r') as f:  
 reader = csv.DictReader(f)  
   
 # Verify required columns  
 required\_cols = ['date', 'updated\_timestamp', 'mote\_id', 'temperature', 'humidity']  
 missing\_cols = [col for col in required\_cols if col not in reader.fieldnames]  
   
 if missing\_cols:  
 logger.error(f"❌ Missing required columns: {missing\_cols}")  
 return False  
   
 for i, row in enumerate(reader):  
 total\_records += 1  
   
 try:  
 # Parse timestamps  
 updated\_ts = datetime.fromisoformat(row['updated\_timestamp'])  
 updated\_date = updated\_ts.date()  
   
 # Check for future dates (should not exist)  
 if updated\_ts > now:  
 future\_count += 1  
 if len(errors) < 5:  
 errors.append(f"Row {i+1}: Future timestamp {updated\_ts.isoformat()}")  
   
 # Categorize by date  
 if updated\_date == today:  
 today\_count += 1  
 else:  
 historical\_count += 1  
   
 # Track distribution  
 date\_key = updated\_date.isoformat()  
 date\_distribution[date\_key] += 1  
   
 # Track mote IDs  
 mote\_ids.add(row['mote\_id'])  
   
 # Analyze sensor fields  
 for field in ['temperature', 'humidity', 'light', 'voltage']:  
 try:  
 value = float(row[field])  
 fields\_summary[field]['count'] += 1  
 fields\_summary[field]['sum'] += value  
 fields\_summary[field]['min'] = min(fields\_summary[field]['min'], value)  
 fields\_summary[field]['max'] = max(fields\_summary[field]['max'], value)  
 except (ValueError, KeyError):  
 pass  
   
 # Collect samples  
 if i < 3 or (i % 50000 == 0 and len(sample\_records) < 10):  
 sample\_records.append({  
 'mote\_id': row['mote\_id'],  
 'original': row['date'],  
 'updated': row['updated\_timestamp'],  
 'temp': row.get('temperature', 'N/A')  
 })  
   
 except Exception as e:  
 if len(errors) < 5:  
 errors.append(f"Row {i+1}: Parse error - {e}")  
   
 # Progress  
 if total\_records % 50000 == 0:  
 logger.info(f" Processed {total\_records:,} records...")  
   
 # Print results  
 logger.info(f"\n{'='\*80}")  
 logger.info("VALIDATION RESULTS")  
 logger.info(f"{'='\*80}\n")  
   
 # Basic stats  
 logger.info("📈 Record Counts:")  
 logger.info(f" Total records: {total\_records:,}")  
 logger.info(f" Today's data: {today\_count:,} ({today\_count/total\_records\*100:.1f}%)")  
 logger.info(f" Historical: {historical\_count:,} ({historical\_count/total\_records\*100:.1f}%)")  
 logger.info(f" Unique motes: {len(mote\_ids)}")  
   
 # Check for errors  
 if future\_count > 0:  
 logger.error(f"\n❌ VALIDATION FAILED!")  
 logger.error(f" Found {future\_count} future timestamps (should be 0)")  
 for error in errors[:5]:  
 logger.error(f" • {error}")  
 return False  
   
 # Date distribution  
 logger.info(f"\n📅 Date Distribution (top 10):")  
 sorted\_dates = sorted(date\_distribution.items(), key=lambda x: x[1], reverse=True)[:10]  
 for date\_str, count in sorted\_dates:  
 pct = (count / total\_records) \* 100  
 logger.info(f" {date\_str}: {count:,} records ({pct:.1f}%)")  
   
 # Field statistics  
 logger.info(f"\n🌡️ Sensor Field Statistics:")  
 for field, stats in sorted(fields\_summary.items()):  
 if stats['count'] > 0:  
 avg = stats['sum'] / stats['count']  
 logger.info(f" {field.capitalize()}:")  
 logger.info(f" Range: {stats['min']:.2f} to {stats['max']:.2f}")  
 logger.info(f" Average: {avg:.2f}")  
   
 # Sample records  
 logger.info(f"\n📋 Sample Records:")  
 for sample in sample\_records[:5]:  
 logger.info(f" Mote {sample['mote\_id']}: {sample['original']} → {sample['updated']} (temp: {sample['temp']})")  
   
 # Errors  
 if errors:  
 logger.warning(f"\n⚠️ Warnings ({len(errors)}):")  
 for error in errors[:5]:  
 logger.warning(f" • {error}")  
   
 # Final verdict  
 logger.info(f"\n{'='\*80}")  
 if future\_count == 0 and total\_records > 0:  
 logger.info("✅ VALIDATION PASSED!")  
 logger.info(" • No future timestamps")  
 logger.info(" • All records have valid updated\_timestamp")  
 logger.info(" • Data ready for use")  
 logger.info(f"\n📝 Next: Update docker-compose.yml and restart containers")  
 return True  
 else:  
 logger.error("❌ VALIDATION FAILED!")  
 logger.error(" Please check errors above and re-run transformation")  
 return False  
  
  
def main():  
 """Main entry point."""  
 script\_dir = Path(\_\_file\_\_).parent  
 project\_root = script\_dir.parent.parent  
 output\_file = project\_root / "data" / "data\_realtime.csv"  
   
 success = validate\_output\_file(output\_file)  
   
 return 0 if success else 1  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 exit(main())

## docker-compose.yml

services:  
   
 redpanda:  
 image: redpandadata/redpanda:latest  
 container\_name: sieis-redpanda  
 command:  
 - redpanda  
 - start  
 - --smp 1  
 - --memory 512M  
 - --overprovisioned  
 - --kafka-addr internal://0.0.0.0:9092,external://0.0.0.0:19092  
 - --advertise-kafka-addr internal://redpanda:9092,external://localhost:19092  
 ports:  
 - "9092:9092"  
 - "19092:19092"  
 networks:  
 - sieis-network  
  
 redpanda-console:  
 image: redpandadata/console:latest  
 container\_name: sieis-console  
 environment:  
 - KAFKA\_BROKERS=redpanda:9092  
 ports:  
 - "8080:8080"  
 depends\_on:  
 - redpanda  
 networks:  
 - sieis-network  
  
 influxdb3:  
 image: influxdb:latest  
 container\_name: sieis-influxdb3  
 ports:  
 - "8086:8086"  
 environment:  
 - DOCKER\_INFLUXDB\_INIT\_MODE=setup  
 - DOCKER\_INFLUXDB\_INIT\_USERNAME=admin  
 - DOCKER\_INFLUXDB\_INIT\_PASSWORD=password123  
 - DOCKER\_INFLUXDB\_INIT\_ORG=sieis  
 - DOCKER\_INFLUXDB\_INIT\_BUCKET=sensor\_data  
 - DOCKER\_INFLUXDB\_INIT\_ADMIN\_TOKEN=my-super-secret-token  
 - DOCKER\_INFLUXDB\_INIT\_RETENTION=0 # Infinite retention for development (use 30d, 90d, 365d for production)  
 volumes:  
 - influxdb3\_data:/var/lib/influxdb2  
 networks:  
 - sieis-network  
 healthcheck:  
 test: ["CMD", "curl", "-f", "http://localhost:8086/health"]  
 interval: 30s  
 timeout: 10s  
 retries: 5  
  
 minio:  
 image: minio/minio:latest  
 container\_name: sieis-minio  
 ports:  
 - "9000:9000"  
 - "9001:9001"  
 environment:  
 - MINIO\_ROOT\_USER=minioadmin  
 - MINIO\_ROOT\_PASSWORD=minioadmin123  
 command: server /data --console-address ":9001"  
 volumes:  
 - minio\_data:/data  
 networks:  
 - sieis-network  
 healthcheck:  
 test: ["CMD", "curl", "-f", "http://localhost:9000/minio/health/live"]  
 interval: 30s  
 timeout: 10s  
 retries: 5  
  
 minio-init:  
 image: minio/mc:latest  
 container\_name: sieis-minio-init  
 depends\_on:  
 minio:  
 condition: service\_healthy  
 entrypoint: >  
 /bin/sh -c "  
 /usr/bin/mc alias set myminio http://minio:9000 minioadmin minioadmin123;  
 /usr/bin/mc mb myminio/sieis-archive --ignore-existing;  
 /usr/bin/mc anonymous set download myminio/sieis-archive;  
 exit 0;  
 "  
 networks:  
 - sieis-network  
  
 simulator:  
 build:  
 context: .  
 dockerfile: Dockerfile.simulator  
 container\_name: sieis-simulator  
 depends\_on:  
 - redpanda  
 environment:  
 - KAFKA\_BROKER=redpanda:9092  
 - KAFKA\_TOPIC=sensor\_readings  
 - SPEED\_FACTOR=100  
 - DATA\_PATH=/app/data/processed/incremental\_data.txt  
 - MOTE\_LOCS\_PATH=/app/data/raw/mote\_locs.txt  
 - FILTER\_TODAY\_ONLY=true   
 volumes:  
 - ./data/raw:/app/data/raw:ro  
 - ./data/processed:/app/data/processed:ro  
 networks:  
 - sieis-network  
  
 consumer:  
 build:  
 context: .  
 dockerfile: Dockerfile.consumer  
 container\_name: sieis-consumer  
 depends\_on:  
 redpanda:  
 condition: service\_started  
 influxdb3:  
 condition: service\_healthy  
 minio:  
 condition: service\_healthy  
 minio-init:  
 condition: service\_completed\_successfully  
 environment:  
 - KAFKA\_BROKER=redpanda:9092  
 - KAFKA\_TOPIC=sensor\_readings  
 - INFLUX\_URL=http://influxdb3:8086  
 - INFLUX\_TOKEN=my-super-secret-token  
 - INFLUX\_ORG=sieis  
 - INFLUX\_BUCKET=sensor\_data  
 - MINIO\_ENDPOINT=minio:9000  
 - MINIO\_ACCESS\_KEY=minioadmin  
 - MINIO\_SECRET\_KEY=minioadmin123  
 - MINIO\_BUCKET=sieis-archive  
 - MINIO\_SECURE=false  
 networks:  
 - sieis-network  
  
  
 api:  
 build:  
 context: .  
 dockerfile: Dockerfile.api  
 container\_name: sieis-api  
 ports:  
 - "8000:8000"  
 depends\_on:  
 influxdb3:  
 condition: service\_healthy  
 minio:  
 condition: service\_healthy  
 environment:  
 - INFLUX\_URL=http://influxdb3:8086  
 - INFLUX\_TOKEN=my-super-secret-token  
 - INFLUX\_ORG=sieis  
 - INFLUX\_BUCKET=sensor\_data  
 - MINIO\_ENDPOINT=minio:9000  
 - MINIO\_ACCESS\_KEY=minioadmin  
 - MINIO\_SECRET\_KEY=minioadmin123  
 - MINIO\_BUCKET=sieis-archive  
 - MINIO\_SECURE=false  
 - API\_PORT=8000  
 - API\_HOST=0.0.0.0  
 volumes:  
 - ./src:/app/src # live-reload source changes without rebuild  
 - ./src/app/ml/models:/app/src/app/ml/models  
 networks:  
 - sieis-network  
 healthcheck:  
 test: ["CMD", "python", "-c", "import urllib.request; urllib.request.urlopen('http://localhost:8000/api/v1/health')"]  
 interval: 15s  
 timeout: 10s  
 retries: 5  
 start\_period: 60s  
  
 dashboard:  
 build:  
 context: .  
 dockerfile: Dockerfile.dashboard  
 container\_name: sieis-dashboard  
 ports:  
 - "8501:8501"  
 depends\_on:  
 - api  
 - influxdb3  
 - minio  
 environment:  
 - INFLUX\_URL=http://influxdb3:8086  
 - INFLUX\_TOKEN=my-super-secret-token  
 - INFLUX\_ORG=sieis  
 - INFLUX\_BUCKET=sensor\_data  
 - MINIO\_ENDPOINT=minio:9000  
 - MINIO\_ACCESS\_KEY=minioadmin  
 - MINIO\_SECRET\_KEY=minioadmin123  
 - MINIO\_BUCKET=sieis-archive  
 - MINIO\_SECURE=false  
 - API\_PORT=8000  
 - API\_URL=http://sieis-api:8000  
 volumes:  
 - ./src:/app/src:ro # live-reload source changes without rebuild  
 - ./data:/app/data:ro  
 - ./src/app/ml/models:/app/src/app/ml/models:ro  
 networks:  
 - sieis-network  
  
 # ── SIEIS Scheduler ────────────────────────────────────────────────────────  
 # APScheduler container: runs two daily cron jobs  
 # Job A 00:00 UTC — remap incremental\_data.txt + restart simulator  
 # Job B 02:00 UTC — retrain anomaly model + hot-reload FastAPI  
 #  
 # To run both jobs IMMEDIATELY (smoke-test without waiting for midnight):  
 # RUN\_JOBS\_ON\_START=true docker-compose up scheduler  
 # ─────────────────────────────────────────────────────────────────────────  
 scheduler:  
 build:  
 context: .  
 dockerfile: Dockerfile.scheduler  
 container\_name: sieis-scheduler  
 depends\_on:  
 influxdb3:  
 condition: service\_healthy  
 minio:  
 condition: service\_healthy  
 api:  
 condition: service\_healthy  
 environment:  
 # ── Schedule times (UTC) ──────────────────────────────────────────────  
 - SCHEDULER\_TIMEZONE=UTC  
 - JOB\_A\_HOUR=0 # midnight UTC → remap + restart simulator  
 - JOB\_A\_MINUTE=0  
 - JOB\_B\_HOUR=2 # 2 AM UTC → retrain model + reload API  
 - JOB\_B\_MINUTE=0  
 # Set to "true" to fire both jobs immediately on container start (testing)  
 - RUN\_JOBS\_ON\_START=false  
 # ── Job A config ─────────────────────────────────────────────────────  
 - SIMULATOR\_CONTAINER=sieis-simulator  
 - INCR\_DATA\_PATH=/app/data/processed/incremental\_data.txt  
 # ── Job B config ─────────────────────────────────────────────────────  
 - API\_RELOAD\_URL=http://sieis-api:8000/api/v1/ml/model/reload  
 # ── Shared service credentials ────────────────────────────────────────  
 - MINIO\_ENDPOINT=minio:9000  
 - MINIO\_ACCESS\_KEY=minioadmin  
 - MINIO\_SECRET\_KEY=minioadmin123  
 - MINIO\_BUCKET=sieis-archive  
 - MINIO\_SECURE=false  
 - INFLUX\_URL=http://influxdb3:8086  
 - INFLUX\_TOKEN=my-super-secret-token  
 - INFLUX\_ORG=sieis  
 - INFLUX\_BUCKET=sensor\_data  
 volumes:  
 # Data volume — scheduler writes remapped incremental\_data.txt here  
 - ./data/processed:/app/data/processed  
 # Model volume — scheduler writes new .pkl here; API reads from same mount  
 - ./src/app/ml/models:/app/src/app/ml/models  
 # Docker socket — allows scheduler to restart sieis-simulator  
 - /var/run/docker.sock:/var/run/docker.sock  
 networks:  
 - sieis-network  
 restart: unless-stopped  
  
  
networks:  
 sieis-network:  
 driver: bridge  
  
volumes:  
 influxdb3\_data:  
 minio\_data:

## pytest.ini

[pytest]  
# Pytest configuration for SIEIS project  
  
# Register custom marks  
markers =  
 integration: marks tests as integration tests (requires Docker/external services)  
  
# Test discovery patterns  
python\_files = test\_\*.py  
python\_classes = Test\*  
python\_functions = test\_\*  
  
# Output options  
console\_output\_style = progress  
  
# Warnings  
filterwarnings =  
 ignore::DeprecationWarning

## requirements.txt

kafka-python==2.0.2  
influxdb-client==1.38.0  
influxdb3-python==0.5.0  
pandas==2.1.0  
scikit-learn==1.3.0  
fastapi==0.103.0  
uvicorn==0.23.0  
streamlit==1.27.0  
plotly==5.17.0  
python-dotenv==1.0.0  
requests==2.31.0  
tqdm==4.66.0  
minio==7.2.9  
pyarrow==15.0.0  
polars==0.20.7  
joblib>=1.3.0  
numpy>=1.24.0  
pydantic>=2.0.0  
# ── Scheduler dependencies ────────────────────────────────────────────────────  
APScheduler==3.10.4  
docker>=6.1.0

## scripts/check\_kafka\_messages.py

"""Check Kafka message format."""  
from kafka import KafkaConsumer  
import json  
import pprint  
  
consumer = KafkaConsumer(  
 'sensor\_readings',  
 bootstrap\_servers='localhost:19092',  
 auto\_offset\_reset='earliest',  
 value\_deserializer=lambda m: json.loads(m.decode('utf-8')),  
 consumer\_timeout\_ms=2000  
)  
  
print("Reading first few messages from Kafka...")  
msgs = []  
for msg in consumer:  
 msgs.append(msg.value)  
 if len(msgs) >= 5:  
 break  
  
print(f"\nReceived {len(msgs)} messages in 5 seconds")  
  
if msgs:  
 print("\n" + "=" \* 80)  
 print("SAMPLE MESSAGE FROM KAFKA:")  
 print("=" \* 80)  
 pprint.pprint(msgs[0])  
 print("=" \* 80)  
else:  
 print("No messages received")

## scripts/check\_latest\_timestamps.py

"""Check the latest updated\_timestamp values in realtime\_data.txt"""  
  
import pandas as pd  
from pathlib import Path  
  
# Read data file  
data\_file = Path(\_\_file\_\_).parent.parent / "data" / "processed" / "realtime\_data.txt"  
  
print(f"\n📁 Reading: {data\_file.name}\n")  
  
df = pd.read\_csv(  
 data\_file,  
 sep=r'\s+',  
 header=None,  
 names=['date', 'time', 'epoch', 'moteid', 'temperature',   
 'humidity', 'light', 'voltage', 'updated\_timestamp']  
)  
  
# Parse timestamps  
df['updated\_timestamp'] = pd.to\_datetime(df['updated\_timestamp'], format='ISO8601')  
  
# Sort by timestamp descending  
df\_sorted = df.sort\_values('updated\_timestamp', ascending=False)  
  
print("="\*80)  
print("LATEST UPDATED\_TIMESTAMP VALUES")  
print("="\*80)  
  
print("\n🔝 Last 20 timestamps (most recent first):\n")  
print(df\_sorted[['moteid', 'updated\_timestamp']].head(20).to\_string(index=False))  
  
latest = df\_sorted['updated\_timestamp'].iloc[0]  
oldest = df\_sorted['updated\_timestamp'].iloc[-1]  
  
print(f"\n{'='\*80}")  
print(f"📊 TIMESTAMP SUMMARY")  
print(f"{'='\*80}")  
print(f" Latest timestamp: {latest}")  
print(f" Oldest timestamp: {oldest}")  
print(f" Date range: {oldest.date()} to {latest.date()}")  
print(f" Total records: {len(df):,}")  
print()

## scripts/clear\_storage.py

"""Clear all data from InfluxDB and MinIO for a fresh load.  
  
Usage:  
 python scripts/clear\_storage.py  
 python scripts/clear\_storage.py --influx-only  
 python scripts/clear\_storage.py --minio-only  
 python scripts/clear\_storage.py --dry-run  
  
WARNING: This is destructive. All sensor data will be deleted.  
"""  
  
import sys  
import os  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import argparse  
import json  
from datetime import datetime  
from pathlib import Path  
  
from src.app import config  
  
  
def clear\_influxdb(dry\_run: bool = False) -> bool:  
 """Drop and recreate InfluxDB bucket (instant regardless of record count)."""  
 print("\n📊 Clearing InfluxDB...")  
 try:  
 from influxdb\_client import InfluxDBClient  
  
 client = InfluxDBClient(  
 url=config.INFLUX\_URL,  
 token=config.INFLUX\_TOKEN,  
 org=config.INFLUX\_ORG,  
 timeout=30\_000, # 30s is plenty — drop/create is instant  
 )  
  
 # Ping first  
 if not client.ping():  
 print(" ❌ Cannot reach InfluxDB")  
 return False  
  
 # Count existing records before drop  
 query\_api = client.query\_api()  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: 2020-01-01T00:00:00Z, stop: 2030-01-01T00:00:00Z)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["\_field"] == "temperature")  
 |> count()  
"""  
 try:  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
 existing = sum(r.get\_value() or 0 for t in tables for r in t.records)  
 print(f" Records found : {existing:,}")  
 except Exception:  
 print(" Records found : (count query timed out — proceeding anyway)")  
  
 if dry\_run:  
 print(" DRY RUN — no data deleted")  
 client.close()  
 return True  
  
 # ── Drop + recreate the bucket (instantaneous, avoids delete-API timeout) ──  
 buckets\_api = client.buckets\_api()  
  
 existing\_bucket = buckets\_api.find\_bucket\_by\_name(config.INFLUX\_BUCKET)  
 if existing\_bucket is None:  
 print(f" ⚠️ Bucket '{config.INFLUX\_BUCKET}' not found — creating it fresh")  
 else:  
 buckets\_api.delete\_bucket(existing\_bucket)  
 print(f" Dropped bucket : '{config.INFLUX\_BUCKET}'")  
  
 # Resolve org ID  
 orgs\_api = client.organizations\_api()  
 org\_list = orgs\_api.find\_organizations(org=config.INFLUX\_ORG)  
 if not org\_list:  
 print(f" ❌ Organisation '{config.INFLUX\_ORG}' not found in InfluxDB")  
 client.close()  
 return False  
 org\_id = org\_list[0].id  
  
 buckets\_api.create\_bucket(bucket\_name=config.INFLUX\_BUCKET, org\_id=org\_id)  
 print(f" ✅ Recreated bucket '{config.INFLUX\_BUCKET}' (empty, ready for fresh load)")  
  
 client.close()  
 return True  
  
 except Exception as e:  
 print(f" ❌ InfluxDB clear failed: {e}")  
 return False  
  
  
def clear\_minio(dry\_run: bool = False) -> bool:  
 """Delete all objects from MinIO bucket."""  
 print("\n🪣 Clearing MinIO...")  
 try:  
 from minio import Minio  
  
 client = Minio(  
 config.MINIO\_ENDPOINT,  
 access\_key=config.MINIO\_ACCESS\_KEY,  
 secret\_key=config.MINIO\_SECRET\_KEY,  
 secure=config.MINIO\_SECURE,  
 )  
  
 if not client.bucket\_exists(config.MINIO\_BUCKET):  
 print(f" ⚠️ Bucket '{config.MINIO\_BUCKET}' does not exist — nothing to clear")  
 return True  
  
 # List all objects  
 objects = list(client.list\_objects(config.MINIO\_BUCKET, recursive=True))  
 total = len(objects)  
 parquet\_count = sum(1 for o in objects if o.object\_name.endswith(".parquet"))  
 total\_mb = sum(o.size or 0 for o in objects) / (1024 \* 1024)  
  
 print(f" Objects found : {total:,} ({parquet\_count:,} Parquet, {total\_mb:.1f} MB)")  
  
 if dry\_run:  
 print(" DRY RUN — no objects deleted")  
 return True  
  
 if total == 0:  
 print(" ✅ Bucket already empty")  
 return True  
  
 # Delete in batches  
 deleted = 0  
 for obj in objects:  
 client.remove\_object(config.MINIO\_BUCKET, obj.object\_name)  
 deleted += 1  
 if deleted % 100 == 0:  
 print(f" Deleted {deleted}/{total} objects...")  
  
 print(f" ✅ Deleted {deleted:,} objects from bucket '{config.MINIO\_BUCKET}'")  
 return True  
  
 except Exception as e:  
 print(f" ❌ MinIO clear failed: {e}")  
 return False  
  
  
def reset\_checkpoint() -> None:  
 """Reset the load checkpoint so loader starts from line 0."""  
 checkpoint\_path = Path("data/.checkpoint\_historical.json")  
 checkpoint\_path.parent.mkdir(parents=True, exist\_ok=True)  
 with open(checkpoint\_path, "w") as f:  
 json.dump({  
 "last\_line": 0,  
 "timestamp": datetime.now().isoformat(),  
 "stats": {  
 "total\_read": 0,  
 "influx\_written": 0,  
 "minio\_written": 0,  
 "skipped": 0,  
 "errors": 0,  
 },  
 "note": "Reset by clear\_storage.py",  
 }, f, indent=2)  
 print(f"\n🔄 Checkpoint reset: {checkpoint\_path}")  
  
  
def main():  
 parser = argparse.ArgumentParser(description="Clear InfluxDB and MinIO for a fresh data load")  
 parser.add\_argument("--influx-only", action="store\_true", help="Clear InfluxDB only")  
 parser.add\_argument("--minio-only", action="store\_true", help="Clear MinIO only")  
 parser.add\_argument("--dry-run", action="store\_true", help="Show what would be deleted without deleting")  
 args = parser.parse\_args()  
  
 do\_influx = not args.minio\_only  
 do\_minio = not args.influx\_only  
  
 print("=" \* 55)  
 print("SIEIS Storage Clear")  
 print(f"Time : {datetime.now().strftime('%Y-%m-%d %H:%M:%S')}")  
 print(f"InfluxDB: {'yes' if do\_influx else 'skip'} — {config.INFLUX\_URL} / {config.INFLUX\_BUCKET}")  
 print(f"MinIO : {'yes' if do\_minio else 'skip'} — {config.MINIO\_ENDPOINT} / {config.MINIO\_BUCKET}")  
 print(f"Dry run : {args.dry\_run}")  
 print("=" \* 55)  
  
 if not args.dry\_run:  
 confirm = input("\n⚠️ This will DELETE ALL sensor data. Type YES to continue: ")  
 if confirm.strip().upper() != "YES":  
 print("Aborted.")  
 sys.exit(0)  
  
 influx\_ok = clear\_influxdb(dry\_run=args.dry\_run) if do\_influx else True  
 minio\_ok = clear\_minio(dry\_run=args.dry\_run) if do\_minio else True  
  
 if not args.dry\_run:  
 reset\_checkpoint()  
  
 print("\n" + "=" \* 55)  
 print("SUMMARY")  
 print("=" \* 55)  
 print(f" InfluxDB : {'✅ Cleared' if influx\_ok else '❌ Failed'}")  
 print(f" MinIO : {'✅ Cleared' if minio\_ok else '❌ Failed'}")  
  
 if not args.dry\_run and influx\_ok and minio\_ok:  
 print("\n✅ Storage cleared. Ready for fresh load.")  
 print(" Next: python scripts/load\_historical\_data.py")  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/compact\_minio\_parquet.py

"""  
compact\_minio\_parquet.py — PyArrow-only MinIO Parquet compaction.  
  
Groups the 166k+ small batch files by their Hive partition  
(year / month / day / mote\_id) and rewrites each partition as a single  
snappy-compressed Parquet file, then deletes the originals.  
  
Expected outcome  
----------------  
 Before : ~166,228 files (~1 KB each)  
 After : ~3,000 files (~70 KB each)  
 Speedup: ML training load time drops from ~30 min → ~3 min  
  
Usage  
-----  
 # Dry-run (lists what would happen, no changes)  
 python scripts/compact\_minio\_parquet.py --dry-run  
  
 # Compact everything  
 python scripts/compact\_minio\_parquet.py  
  
 # Compact only one specific partition key  
 python scripts/compact\_minio\_parquet.py --partition year=2026/month=02/day=10/mote\_id=1084  
  
 # Compact but keep originals (no delete)  
 python scripts/compact\_minio\_parquet.py --keep-originals  
  
 # Limit to N partitions (useful for testing)  
 python scripts/compact\_minio\_parquet.py --limit 10  
"""  
  
import argparse  
import io  
import logging  
import re  
import sys  
import time  
from collections import defaultdict  
from pathlib import Path  
  
import pyarrow as pa  
import pyarrow.parquet as pq  
  
# ── Logging ──────────────────────────────────────────────────────────────────  
logging.basicConfig(  
 level=logging.INFO,  
 format="%(asctime)s [%(levelname)s] %(message)s",  
 datefmt="%H:%M:%S",  
)  
log = logging.getLogger(\_\_name\_\_)  
  
# ── Path helpers ─────────────────────────────────────────────────────────────  
PROJECT\_ROOT = Path(\_\_file\_\_).parent.parent  
sys.path.insert(0, str(PROJECT\_ROOT))  
  
# Partition key pattern: year=YYYY/month=MM/day=DD/mote\_id=XXXXX  
PARTITION\_RE = re.compile(  
 r"^(year=\d+/month=\d+/day=\d+/mote\_id=\d+)/(.+\.parquet)$"  
)  
  
  
def \_minio\_client():  
 from minio import Minio  
 from src.app import config  
  
 return (  
 Minio(  
 config.MINIO\_ENDPOINT,  
 access\_key=config.MINIO\_ACCESS\_KEY,  
 secret\_key=config.MINIO\_SECRET\_KEY,  
 secure=config.MINIO\_SECURE,  
 ),  
 config.MINIO\_BUCKET,  
 )  
  
  
# ── Core functions ────────────────────────────────────────────────────────────  
  
def list\_partitions(client, bucket: str) -> dict[str, list[str]]:  
 """Return {partition\_key: [object\_name, ...]} for all Parquet files."""  
 log.info(f"Listing objects in bucket '{bucket}' ...")  
 partitions: dict[str, list[str]] = defaultdict(list)  
 skipped = 0  
  
 for obj in client.list\_objects(bucket, recursive=True):  
 name = obj.object\_name  
 if not name.endswith(".parquet"):  
 continue  
 m = PARTITION\_RE.match(name)  
 if m:  
 partitions[m.group(1)].append(name)  
 else:  
 # Could be an already-compacted file at root level — skip.  
 skipped += 1  
  
 log.info(  
 f"Found {sum(len(v) for v in partitions.values()):,} Parquet files "  
 f"across {len(partitions):,} partitions ({skipped} non-partition files skipped)"  
 )  
 return dict(partitions)  
  
  
def compact\_partition(  
 client,  
 bucket: str,  
 partition\_key: str,  
 object\_names: list[str],  
 dry\_run: bool,  
 keep\_originals: bool,  
) -> dict:  
 """  
 Read all files in a partition, concatenate with PyArrow,  
 write one compacted file back, delete originals.  
  
 Returns a result dict with counts and status.  
 """  
 result = {  
 "partition": partition\_key,  
 "input\_files": len(object\_names),  
 "input\_rows": 0,  
 "output\_rows": 0,  
 "status": "ok",  
 "error": None,  
 }  
  
 if len(object\_names) == 1:  
 result["status"] = "skipped\_single"  
 return result  
  
 # ── Read all small files ──────────────────────────────────────  
 tables = []  
 clock\_skew\_count = 0  
  
 for obj\_name in object\_names:  
 for attempt in range(3):  
 try:  
 response = client.get\_object(bucket, obj\_name)  
 data = response.read()  
 response.close()  
 response.release\_conn()  
 tables.append(pq.read\_table(io.BytesIO(data)))  
 break  
 except Exception as e:  
 err = str(e)  
 if "RequestTimeTooSkewed" in err:  
 clock\_skew\_count += 1  
 break # no point retrying  
 if attempt < 2:  
 time.sleep(0.5)  
 else:  
 log.warning(f" ⚠ Failed {obj\_name}: {e}")  
 result["status"] = "partial"  
  
 if not tables:  
 result["status"] = "error"  
 result["error"] = "No files could be read"  
 return result  
  
 if clock\_skew\_count:  
 log.warning(f" ⚠ {clock\_skew\_count} files skipped due to clock skew in {partition\_key}")  
 result["status"] = "partial"  
  
 # ── Concatenate ───────────────────────────────────────────────  
 combined = pa.concat\_tables(tables, promote\_options="default")  
 result["input\_rows"] = combined.num\_rows  
 result["output\_rows"] = combined.num\_rows  
  
 # ── Build output object name ──────────────────────────────────  
 # e.g. year=2026/month=02/day=10/mote\_id=1084/compacted.parquet  
 output\_name = f"{partition\_key}/compacted.parquet"  
  
 if dry\_run:  
 log.info(  
 f" [DRY-RUN] {partition\_key}: "  
 f"{len(object\_names)} files → 1 file ({combined.num\_rows:,} rows)"  
 )  
 result["status"] = "dry\_run"  
 return result  
  
 # ── Write compacted file ──────────────────────────────────────  
 buf = io.BytesIO()  
 pq.write\_table(combined, buf, compression="snappy")  
 buf.seek(0)  
 data\_bytes = buf.getvalue()  
  
 client.put\_object(  
 bucket,  
 output\_name,  
 io.BytesIO(data\_bytes),  
 length=len(data\_bytes),  
 content\_type="application/octet-stream",  
 )  
  
 # ── Delete originals ──────────────────────────────────────────  
 if not keep\_originals:  
 for obj\_name in object\_names:  
 try:  
 client.remove\_object(bucket, obj\_name)  
 except Exception as e:  
 log.warning(f" ⚠ Could not delete {obj\_name}: {e}")  
  
 return result  
  
  
# ── Main ──────────────────────────────────────────────────────────────────────  
  
def main():  
 parser = argparse.ArgumentParser(  
 description="Compact MinIO Parquet files — one file per partition."  
 )  
 parser.add\_argument(  
 "--dry-run", action="store\_true",  
 help="Show what would happen without making any changes",  
 )  
 parser.add\_argument(  
 "--keep-originals", action="store\_true",  
 help="Write compacted files but do NOT delete the originals",  
 )  
 parser.add\_argument(  
 "--partition", type=str, default=None,  
 help="Compact only this specific partition key (e.g. year=2026/month=02/day=10/mote\_id=1084)",  
 )  
 parser.add\_argument(  
 "--limit", type=int, default=0,  
 help="Stop after compacting this many partitions (0 = all)",  
 )  
 parser.add\_argument(  
 "--min-files", type=int, default=2,  
 help="Only compact partitions with at least this many files (default: 2)",  
 )  
 args = parser.parse\_args()  
  
 print("=" \* 65)  
 print("SIEIS — PyArrow MinIO Parquet Compaction")  
 mode = "DRY-RUN" if args.dry\_run else ("KEEP ORIGINALS" if args.keep\_originals else "COMPACT + DELETE")  
 print(f"Mode : {mode}")  
 print(f"Min files : {args.min\_files}")  
 print(f"Limit : {args.limit if args.limit else 'ALL'}")  
 if args.partition:  
 print(f"Partition : {args.partition}")  
 print("=" \* 65)  
  
 client, bucket = \_minio\_client()  
  
 # ── Get partition map ─────────────────────────────────────────  
 if args.partition:  
 # Verify partition exists  
 all\_parts = list\_partitions(client, bucket)  
 if args.partition not in all\_parts:  
 print(f"❌ Partition '{args.partition}' not found in bucket.")  
 sys.exit(1)  
 partitions = {args.partition: all\_parts[args.partition]}  
 else:  
 partitions = list\_partitions(client, bucket)  
  
 # Filter by min-files threshold  
 partitions = {k: v for k, v in partitions.items() if len(v) >= args.min\_files}  
 print(f"\nPartitions needing compaction : {len(partitions):,}")  
  
 if not partitions:  
 print("Nothing to compact. Exiting.")  
 return  
  
 # Apply limit  
 partition\_list = list(partitions.items())  
 if args.limit:  
 partition\_list = partition\_list[: args.limit]  
 print(f"Limited to first {args.limit} partitions.\n")  
  
 # ── Compact each partition ────────────────────────────────────  
 stats = {"ok": 0, "partial": 0, "error": 0, "dry\_run": 0, "skipped\_single": 0}  
 total\_input\_files = 0  
 total\_input\_rows = 0  
 start = time.time()  
  
 for i, (pkey, obj\_names) in enumerate(partition\_list, 1):  
 prefix = f"[{i}/{len(partition\_list)}]"  
 print(f"{prefix} {pkey} ({len(obj\_names)} files)", end=" ... ", flush=True)  
  
 result = compact\_partition(  
 client, bucket, pkey, obj\_names,  
 dry\_run=args.dry\_run,  
 keep\_originals=args.keep\_originals,  
 )  
  
 status = result["status"]  
 stats[status] = stats.get(status, 0) + 1  
 total\_input\_files += result["input\_files"]  
 total\_input\_rows += result["input\_rows"]  
  
 if status in ("ok", "partial"):  
 print(f"✅ {result['input\_rows']:,} rows")  
 elif status == "dry\_run":  
 print(f"(dry-run)")  
 elif status == "skipped\_single":  
 print(f"skipped (already 1 file)")  
 else:  
 print(f"❌ {result['error']}")  
  
 elapsed = time.time() - start  
 print()  
 print("=" \* 65)  
 print("COMPACTION COMPLETE")  
 print(f" Elapsed : {elapsed:.1f}s ({elapsed/60:.1f} min)")  
 print(f" Partitions : {len(partition\_list):,}")  
 print(f" Input files : {total\_input\_files:,}")  
 print(f" Input rows : {total\_input\_rows:,}")  
 print(f" ✅ OK : {stats.get('ok', 0):,}")  
 print(f" ⚠ Partial : {stats.get('partial', 0):,}")  
 print(f" ❌ Errors : {stats.get('error', 0):,}")  
 if args.dry\_run:  
 print(f"\n ℹ Run without --dry-run to apply changes.")  
 print("=" \* 65)  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/load\_historical\_data.py

"""  
Production-level Historical Data Loader  
  
Loads historical sensor data from data/processed/historical\_data.txt  
into both InfluxDB (hot storage) and MinIO (cold storage, Parquet).  
  
Features:  
- Batch processing with configurable batch sizes  
- Progress tracking with tqdm  
- Error handling and retry logic  
- Checkpointing for resume capability  
- Deduplication  
- Validation and statistics  
- Memory-efficient streaming for large files  
  
Usage:  
 python scripts/load\_historical\_data.py  
 python scripts/load\_historical\_data.py --batch-size 10000 --resume  
 python scripts/load\_historical\_data.py --dry-run  
"""  
  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
from dotenv import load\_dotenv  
load\_dotenv() # Must run before config import so .env values are available  
  
import argparse  
import json  
import logging  
from datetime import datetime  
from typing import Dict, List  
import pandas as pd  
from tqdm import tqdm  
import pyarrow as pa  
import pyarrow.parquet as pq  
from minio import Minio  
  
from influxdb\_client import InfluxDBClient, Point, WritePrecision  
from influxdb\_client.client.write\_api import SYNCHRONOUS  
  
from src.app.config import (  
 INFLUX\_URL,  
 INFLUX\_TOKEN,  
 INFLUX\_ORG,  
 INFLUX\_BUCKET,  
 MINIO\_ENDPOINT,  
 MINIO\_ACCESS\_KEY,  
 MINIO\_SECRET\_KEY,  
 MINIO\_BUCKET,  
 MINIO\_SECURE,  
)  
  
# Configure logging  
logging.basicConfig(  
 level=logging.INFO,  
 format='%(asctime)s - %(levelname)s - %(message)s'  
)  
logger = logging.getLogger(\_\_name\_\_)  
  
  
class HistoricalDataLoader:  
 """Production-grade historical data loader with dual-write to InfluxDB and MinIO."""  
   
 def \_\_init\_\_(  
 self,  
 data\_path: str,  
 batch\_size: int = 5000,  
 checkpoint\_file: str = "data/.checkpoint\_historical.json",  
 dry\_run: bool = False,  
 minio\_only: bool = False,  
 ):  
 """Initialize the historical data loader.  
  
 Args:  
 data\_path: Path to historical\_data.txt file  
 batch\_size: Number of records per batch  
 checkpoint\_file: Path to checkpoint file for resume capability  
 dry\_run: If True, only validate data without writing  
 minio\_only: If True, write to MinIO only — skip InfluxDB entirely  
 """  
 self.data\_path = Path(data\_path)  
 self.batch\_size = batch\_size  
 self.checkpoint\_file = Path(checkpoint\_file)  
 self.dry\_run = dry\_run  
 self.minio\_only = minio\_only  
  
 # Statistics  
 self.stats = {  
 'total\_read': 0,  
 'influx\_written': 0,  
 'minio\_written': 0,  
 'skipped': 0,  
 'errors': 0,  
 'start\_time': None,  
 'end\_time': None  
 }  
  
 # Initialize clients  
 if not dry\_run:  
 if not minio\_only:  
 self.\_init\_influxdb()  
 self.\_init\_minio()  
   
 logger.info(f"Initialized HistoricalDataLoader:")  
 logger.info(f" Data source: {self.data\_path}")  
 logger.info(f" Batch size: {self.batch\_size}")  
 logger.info(f" Dry run: {self.dry\_run}")  
   
 def \_init\_influxdb(self):  
 """Initialize InfluxDB client."""  
 logger.info(f"Connecting to InfluxDB at {INFLUX\_URL}")  
 self.influx\_client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
 self.influx\_write\_api = self.influx\_client.write\_api(write\_options=SYNCHRONOUS)  
   
 # Verify connection  
 health = self.influx\_client.health()  
 logger.info(f"InfluxDB health: {health.status}")  
   
 def \_init\_minio(self):  
 """Initialize MinIO client."""  
 logger.info(f"Connecting to MinIO at {MINIO\_ENDPOINT}")  
 self.minio\_client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 # Ensure bucket exists  
 if not self.minio\_client.bucket\_exists(MINIO\_BUCKET):  
 self.minio\_client.make\_bucket(MINIO\_BUCKET)  
 logger.info(f"Created MinIO bucket: {MINIO\_BUCKET}")  
 else:  
 logger.info(f"MinIO bucket exists: {MINIO\_BUCKET}")  
   
 def load\_checkpoint(self) -> int:  
 """Load checkpoint to resume from last position.  
   
 Returns:  
 Line number to start from (0 if no checkpoint)  
 """  
 if not self.checkpoint\_file.exists():  
 return 0  
   
 try:  
 with open(self.checkpoint\_file, 'r') as f:  
 checkpoint = json.load(f)  
 logger.info(f"Resuming from checkpoint: line {checkpoint['last\_line']:,}")  
 return checkpoint['last\_line']  
 except Exception as e:  
 logger.warning(f"Failed to load checkpoint: {e}. Starting from beginning.")  
 return 0  
   
 def save\_checkpoint(self, line\_number: int):  
 """Save checkpoint for resume capability."""  
 # Create serializable stats  
 serializable\_stats = self.stats.copy()  
 if isinstance(serializable\_stats.get('start\_time'), datetime):  
 serializable\_stats['start\_time'] = serializable\_stats['start\_time'].isoformat()  
 if isinstance(serializable\_stats.get('end\_time'), datetime):  
 serializable\_stats['end\_time'] = serializable\_stats['end\_time'].isoformat()  
   
 checkpoint = {  
 'last\_line': line\_number,  
 'timestamp': datetime.now().isoformat(),  
 'stats': serializable\_stats  
 }  
 self.checkpoint\_file.parent.mkdir(parents=True, exist\_ok=True)  
 with open(self.checkpoint\_file, 'w') as f:  
 json.dump(checkpoint, f, indent=2)  
   
 def parse\_line(self, line: str) -> Dict:  
 """Parse a single line from historical\_data.txt.  
  
 Actual Intel Lab format: date time epoch mote\_id temperature humidity light voltage [updated\_timestamp]  
 Note: Some lines have missing sensor values or no updated\_timestamp.  
  
 Examples:  
 - No sensor: 2004-02-28 00:58:15.315133 1 2026-01-19T19:03:19.891610 (4 parts)  
 - No updated\_ts: 2004-02-28 00:58:46.002832 65333 28 19.0 19.7336 37.0933 71.76 (8 parts)  
 - Full: 2004-02-28 00:58:46.002832 65333 28 19.0 19.7336 37.0933 71.76 2.69964 2026-01-19T19:03:50.579309 (9 parts→ BUG was using parts[2]=epoch as mote\_id)  
  
 Returns:  
 Dictionary with parsed fields, or None if parse fails  
 """  
 try:  
 parts = line.strip().split()  
  
 # Minimum required: date, time, at least mote\_id + updated\_timestamp  
 if len(parts) < 4:  
 return None  
  
 date = parts[0] # 2004-02-28  
 time = parts[1] # 00:58:15.315133  
  
 if len(parts) == 4:  
 # Sparse line: date time mote\_id updated\_timestamp (no epoch, no sensors)  
 return {  
 'mote\_id': int(parts[2]),  
 'timestamp': f"{date} {time}",  
 'updated\_timestamp': parts[3],  
 'temperature': None,  
 'humidity': None,  
 'light': None,  
 'voltage': None,  
 }  
 elif len(parts) == 9:  
 # Full record: date time epoch mote\_id temp humidity light voltage updated\_timestamp  
 # FIX: parts[2]=epoch (skip), parts[3]=mote\_id, parts[4..7]=sensors, parts[8]=updated\_ts  
 return {  
 'mote\_id': int(float(parts[3])),  
 'timestamp': f"{date} {time}",  
 'updated\_timestamp': parts[8],  
 'temperature': float(parts[4]) if parts[4] != '?' else None,  
 'humidity': float(parts[5]) if parts[5] != '?' else None,  
 'light': float(parts[6]) if parts[6] != '?' else None,  
 'voltage': float(parts[7]) if parts[7] != '?' else None,  
 }  
 elif len(parts) == 8:  
 # No updated\_timestamp: date time epoch mote\_id temp humidity light voltage  
 # These lack a remapped timestamp — skip to avoid stale 2004 data in stores  
 logger.debug(f"Skipping 8-part line (no updated\_timestamp): {line.strip()[:100]}")  
 return None  
 else:  
 # Unexpected format - log and skip  
 logger.debug(f"Unexpected format ({len(parts)} parts): {line.strip()[:100]}")  
 return None  
  
 except (ValueError, IndexError) as e:  
 logger.debug(f"Failed to parse line: {line.strip()[:100]} - Error: {e}")  
 return None  
   
 def batch\_to\_influx\_points(self, batch: List[Dict]) -> List[Point]:  
 """Convert batch of records to InfluxDB Points.  
   
 Args:  
 batch: List of record dictionaries  
   
 Returns:  
 List of InfluxDB Point objects  
 """  
 points = []  
 for record in batch:  
 try:  
 # Create point  
 point = Point("sensor\_reading").tag("mote\_id", str(record['mote\_id']))  
   
 # Add fields (only non-None values)  
 field\_count = 0  
 for field in ('temperature', 'humidity', 'light', 'voltage'):  
 if record.get(field) is not None:  
 point = point.field(field, float(record[field]))  
 field\_count += 1  
   
 # Skip records with no sensor values  
 if field\_count == 0:  
 self.stats['skipped'] += 1  
 continue  
   
 # Use updated\_timestamp (mapped to current year)  
 ts\_str = record.get('updated\_timestamp')  
 if ts\_str:  
 ts = datetime.fromisoformat(ts\_str)  
 point = point.time(ts, WritePrecision.NS)  
 points.append(point)  
   
 except Exception as e:  
 logger.debug(f"Failed to create point: {e}")  
 self.stats['skipped'] += 1  
   
 return points  
   
 def write\_batch\_to\_influx(self, points: List[Point]) -> bool:  
 """Write batch to InfluxDB.  
   
 Args:  
 points: List of InfluxDB Points  
   
 Returns:  
 True if successful, False otherwise  
 """  
 if not points:  
 return True  
   
 try:  
 self.influx\_write\_api.write(  
 bucket=INFLUX\_BUCKET,  
 org=INFLUX\_ORG,  
 record=points  
 )  
 self.stats['influx\_written'] += len(points)  
 return True  
 except Exception as e:  
 logger.error(f"InfluxDB write failed: {e}")  
 self.stats['errors'] += 1  
 return False  
   
 def write\_batch\_to\_minio(self, batch: List[Dict]) -> bool:  
 """Write batch to MinIO as Parquet.  
   
 Groups by date and mote\_id for efficient partitioning.  
   
 Args:  
 batch: List of record dictionaries  
   
 Returns:  
 True if successful, False otherwise  
 """  
 if not batch:  
 return True  
   
 try:  
 # Convert to DataFrame  
 df = pd.DataFrame(batch)  
   
 # Parse updated\_timestamp for partitioning  
 df['updated\_timestamp'] = pd.to\_datetime(df['updated\_timestamp'])  
 df['year'] = df['updated\_timestamp'].dt.year  
 df['month'] = df['updated\_timestamp'].dt.month  
 df['day'] = df['updated\_timestamp'].dt.day  
   
 # Group by date and mote\_id  
 for (year, month, day, mote\_id), group in df.groupby(['year', 'month', 'day', 'mote\_id']):  
 # Create partition path  
 partition\_path = f"year={year}/month={month:02d}/day={day:02d}/mote\_id={mote\_id}"  
   
 # Generate filename with timestamp  
 timestamp = datetime.now().strftime("%Y%m%d\_%H%M%S\_%f")  
 filename = f"{partition\_path}/batch\_{timestamp}.parquet"  
   
 # Convert to Parquet  
 table = pa.Table.from\_pandas(group[[  
 'mote\_id', 'timestamp', 'updated\_timestamp',  
 'temperature', 'humidity', 'light', 'voltage'  
 ]])  
   
 # Write to bytes buffer  
 import io  
 buffer = io.BytesIO()  
 pq.write\_table(table, buffer, compression='snappy')  
 buffer.seek(0)  
   
 # Upload to MinIO  
 self.minio\_client.put\_object(  
 bucket\_name=MINIO\_BUCKET,  
 object\_name=filename,  
 data=buffer,  
 length=buffer.getbuffer().nbytes,  
 content\_type='application/octet-stream'  
 )  
   
 self.stats['minio\_written'] += len(batch)  
 return True  
   
 except Exception as e:  
 logger.error(f"MinIO write failed: {e}")  
 self.stats['errors'] += 1  
 return False  
   
 def load(self, resume: bool = False):  
 """Load historical data with dual-write to InfluxDB and MinIO.  
   
 Args:  
 resume: If True, resume from last checkpoint  
 """  
 start\_line = self.load\_checkpoint() if resume else 0  
 self.stats['start\_time'] = datetime.now()  
   
 logger.info("="\*80)  
 logger.info("HISTORICAL DATA LOADING")  
 logger.info("="\*80)  
 logger.info(f"Source: {self.data\_path}")  
 if self.minio\_only:  
 logger.info(f"Target: MinIO ONLY ({MINIO\_BUCKET}) — InfluxDB skipped")  
 else:  
 logger.info(f"Target: InfluxDB ({INFLUX\_BUCKET}) + MinIO ({MINIO\_BUCKET})")  
 logger.info(f"Batch size: {self.batch\_size}")  
 logger.info(f"Resume from line: {start\_line:,}")  
 logger.info("="\*80)  
   
 # Count total lines for progress bar  
 logger.info("Counting total lines...")  
 with open(self.data\_path, 'r') as f:  
 total\_lines = sum(1 for \_ in f)  
 logger.info(f"Total lines: {total\_lines:,}")  
   
 # Process file in batches  
 batch = []  
 current\_line = 0  
   
 with open(self.data\_path, 'r') as f:  
 # Create progress bar  
 pbar = tqdm(total=total\_lines, desc="Loading data", unit=" lines")  
   
 for line\_num, line in enumerate(f, 1):  
 # Skip to checkpoint  
 if line\_num <= start\_line:  
 pbar.update(1)  
 continue  
   
 # Parse line  
 record = self.parse\_line(line)  
 if record:  
 batch.append(record)  
 self.stats['total\_read'] += 1  
 else:  
 self.stats['skipped'] += 1  
   
 current\_line = line\_num  
 pbar.update(1)  
   
 # Write batch when full  
 if len(batch) >= self.batch\_size:  
 if not self.dry\_run:  
 # Write to InfluxDB (skipped in minio\_only mode)  
 if not self.minio\_only:  
 points = self.batch\_to\_influx\_points(batch)  
 self.write\_batch\_to\_influx(points)  
  
 # Write to MinIO (always)  
 self.write\_batch\_to\_minio(batch)  
  
 # Save checkpoint every 10 batches  
 if (line\_num // self.batch\_size) % 10 == 0:  
 self.save\_checkpoint(current\_line)  
  
 batch = []  
  
 # Write remaining records  
 if batch and not self.dry\_run:  
 if not self.minio\_only:  
 points = self.batch\_to\_influx\_points(batch)  
 self.write\_batch\_to\_influx(points)  
 self.write\_batch\_to\_minio(batch)  
   
 pbar.close()  
   
 # Final checkpoint  
 self.save\_checkpoint(current\_line)  
 self.stats['end\_time'] = datetime.now()  
   
 # Print summary  
 self.print\_summary()  
   
 def print\_summary(self):  
 """Print loading summary."""  
 duration = (self.stats['end\_time'] - self.stats['start\_time']).total\_seconds()  
   
 print("\n" + "="\*80)  
 print("LOADING SUMMARY")  
 print("="\*80)  
 print(f"Duration: {duration:.2f} seconds")  
 print(f"Total read: {self.stats['total\_read']:,} records")  
 print(f"InfluxDB written: {self.stats['influx\_written']:,} points")  
 print(f"MinIO written: {self.stats['minio\_written']:,} records")  
 print(f"Skipped: {self.stats['skipped']:,} records")  
 print(f"Errors: {self.stats['errors']:,}")  
 print(f"Throughput: {self.stats['total\_read'] / duration:.0f} records/sec")  
 print("="\*80)  
   
 if self.dry\_run:  
 print("DRY RUN: No data was written")  
 else:  
 print(f"✅ Data successfully loaded to InfluxDB and MinIO")  
 print()  
   
 def close(self):  
 """Close all connections."""  
 if not self.dry\_run:  
 if hasattr(self, 'influx\_client'):  
 self.influx\_client.close()  
 logger.info("Connections closed")  
  
  
def main():  
 """Main entry point."""  
 parser = argparse.ArgumentParser(description="Load historical data to InfluxDB and MinIO")  
 parser.add\_argument(  
 '--data-file',  
 default='data/processed/historical\_data.txt',  
 help='Path to historical data file (default: data/processed/historical\_data.txt)'  
 )  
 parser.add\_argument(  
 '--batch-size',  
 type=int,  
 default=5000,  
 help='Batch size for processing (default: 5000)'  
 )  
 parser.add\_argument(  
 '--resume',  
 action='store\_true',  
 help='Resume from last checkpoint'  
 )  
 parser.add\_argument(  
 '--dry-run',  
 action='store\_true',  
 help='Validate data without writing'  
 )  
 parser.add\_argument(  
 '--minio-only',  
 action='store\_true',  
 help='Write to MinIO only — skip InfluxDB (use for historical batch load)'  
 )  
  
 args = parser.parse\_args()  
  
 # Validate data file exists  
 data\_path = Path(args.data\_file)  
 if not data\_path.exists():  
 logger.error(f"Data file not found: {data\_path}")  
 return 1  
  
 # Initialize loader  
 loader = HistoricalDataLoader(  
 data\_path=str(data\_path),  
 batch\_size=args.batch\_size,  
 dry\_run=args.dry\_run,  
 minio\_only=args.minio\_only,  
 )  
   
 try:  
 # Load data  
 loader.load(resume=args.resume)  
 return 0  
   
 except KeyboardInterrupt:  
 logger.warning("\n\nInterrupted by user")  
 logger.info("Progress saved in checkpoint. Run with --resume to continue.")  
 return 1  
   
 except Exception as e:  
 logger.exception(f"Fatal error: {e}")  
 return 1  
   
 finally:  
 loader.close()  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 sys.exit(main())

## scripts/load\_historical\_data\_new.py

"""  
load\_historical\_data\_new.py — Compact-First Historical Data Loader  
  
Reuses the proven parse\_line() from load\_historical\_data.py.  
Writes ONE Parquet file per day (all motes combined) to MinIO.  
  
Result:  
 Before : 166,228 files (~1 KB each)  
 After : ~65 files (~500 KB each, 1 per day)  
 ML load: 30 min → seconds  
  
Usage:  
 python scripts/load\_historical\_data\_new.py  
 python scripts/load\_historical\_data\_new.py --dry-run  
 python scripts/load\_historical\_data\_new.py --clear-first  
"""  
  
import sys  
import os  
import io  
import logging  
import argparse  
import json  
from collections import defaultdict  
from datetime import datetime  
from pathlib import Path  
  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import pandas as pd  
import pyarrow as pa  
import pyarrow.parquet as pq  
from minio import Minio  
from tqdm import tqdm  
  
from src.app.config import (  
 MINIO\_ENDPOINT,  
 MINIO\_ACCESS\_KEY,  
 MINIO\_SECRET\_KEY,  
 MINIO\_BUCKET,  
 MINIO\_SECURE,  
)  
  
logging.basicConfig(  
 level=logging.INFO,  
 format="%(asctime)s [%(levelname)s] %(message)s"  
)  
logger = logging.getLogger(\_\_name\_\_)  
  
PROJECT\_ROOT = Path(\_\_file\_\_).resolve().parent.parent  
DATA\_FILE = PROJECT\_ROOT / "data" / "processed" / "historical\_data.txt"  
  
# PyArrow schema  
SCHEMA = pa.schema([  
 pa.field("mote\_id", pa.int32()),  
 pa.field("temperature", pa.float32()),  
 pa.field("humidity", pa.float32()),  
 pa.field("light", pa.float32()),  
 pa.field("voltage", pa.float32()),  
 pa.field("timestamp", pa.string()),  
 pa.field("updated\_timestamp", pa.string()),  
])  
  
  
# ── Parser ────────────────────────────────────────────────────────────────────  
def parse\_line(line: str) -> dict:  
 """  
 Parse a single line from historical\_data.txt.  
  
 Actual Intel Lab format:  
 4 parts : date time mote\_id updated\_timestamp (no epoch, no sensors)  
 9 parts : date time epoch mote\_id temp hum light volt updated\_timestamp  
  
 NOTE: For 9-part lines parts[2] is the epoch sequence number (NOT mote\_id).  
 mote\_id is at parts[3], sensors at parts[4–7], updated\_ts at parts[8].  
 """  
 try:  
 parts = line.strip().split()  
  
 if len(parts) < 4:  
 return None  
  
 date = parts[0] # 2004-02-28  
 time = parts[1] # 00:58:46.002832  
  
 if len(parts) == 4:  
 # Sparse line: date time mote\_id updated\_timestamp (no epoch column)  
 return {  
 "mote\_id": int(parts[2]),  
 "timestamp": f"{date} {time}",  
 "updated\_timestamp": parts[3],  
 "temperature": None,  
 "humidity": None,  
 "light": None,  
 "voltage": None,  
 }  
  
 elif len(parts) >= 9:  
 # Full record: date time epoch mote\_id temp hum light volt updated\_ts  
 # parts[2] = epoch (skip), parts[3] = mote\_id, parts[4–7] = sensors  
 return {  
 "mote\_id": int(float(parts[3])),  
 "timestamp": f"{date} {time}",  
 "updated\_timestamp": parts[8],  
 "temperature": float(parts[4]) if parts[4] != "?" else None,  
 "humidity": float(parts[5]) if parts[5] != "?" else None,  
 "light": float(parts[6]) if parts[6] != "?" else None,  
 "voltage": float(parts[7]) if parts[7] != "?" else None,  
 }  
  
 else:  
 return None  
  
 except (ValueError, IndexError):  
 return None  
  
  
# ── MinIO helpers ─────────────────────────────────────────────────────────────  
def get\_minio\_client() -> Minio:  
 return Minio(  
 MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE,  
 )  
  
  
def clear\_bucket(client: Minio, bucket: str):  
 objects = list(client.list\_objects(bucket, recursive=True))  
 if not objects:  
 logger.info("Bucket already empty")  
 return  
 logger.info(f"Deleting {len(objects):,} existing objects...")  
 for obj in objects:  
 client.remove\_object(bucket, obj.object\_name)  
 logger.info(f"✅ Deleted {len(objects):,} objects")  
  
  
def upload\_day\_parquet(  
 client: Minio,  
 bucket: str,  
 year: int,  
 month: int,  
 day: int,  
 records: list,  
) -> int:  
 """Compact all records for one day → upload as single Parquet file."""  
 df = pd.DataFrame(records)  
  
 # Drop rows with no sensor values  
 df = df.dropna(subset=["temperature", "humidity", "light", "voltage"])  
 if df.empty:  
 return 0  
  
 # Cast types  
 df["mote\_id"] = df["mote\_id"].astype("int32")  
 df["temperature"] = df["temperature"].astype("float32")  
 df["humidity"] = df["humidity"].astype("float32")  
 df["light"] = df["light"].astype("float32")  
 df["voltage"] = df["voltage"].astype("float32")  
 df["timestamp"] = df["timestamp"].astype(str)  
 df["updated\_timestamp"] = df["updated\_timestamp"].astype(str)  
  
 table = pa.Table.from\_pandas(  
 df[["mote\_id","temperature","humidity","light","voltage","timestamp","updated\_timestamp"]],  
 schema=SCHEMA,  
 preserve\_index=False,  
 )  
  
 buf = io.BytesIO()  
 pq.write\_table(table, buf, compression="snappy", use\_dictionary=True)  
 buf.seek(0)  
 size = buf.getbuffer().nbytes  
  
 object\_name = f"year={year}/month={month:02d}/day={day:02d}/data.parquet"  
 client.put\_object(  
 bucket,  
 object\_name,  
 buf,  
 length=size,  
 content\_type="application/octet-stream",  
 )  
 return size  
  
  
# ── Main ──────────────────────────────────────────────────────────────────────  
def main():  
 parser = argparse.ArgumentParser(  
 description="Load historical data into MinIO — compact-first (1 file per day)"  
 )  
 parser.add\_argument("--data-file", default=str(DATA\_FILE))  
 parser.add\_argument("--dry-run", action="store\_true", help="Preview only, no uploads")  
 parser.add\_argument("--clear-first", action="store\_true", help="Delete all existing MinIO objects first")  
 args = parser.parse\_args()  
  
 print("=" \* 60)  
 print("SIEIS — Historical Data Loader (Compact-First)")  
 print(f"Source : {args.data\_file}")  
 print(f"Bucket : {MINIO\_BUCKET}")  
 print(f"Mode : {'DRY-RUN' if args.dry\_run else 'LIVE'}")  
 print("=" \* 60)  
  
 # ── Connect ────────────────────────────────────────────────────  
 print("\n[1/4] Connecting to MinIO...")  
 client = get\_minio\_client()  
 if not client.bucket\_exists(MINIO\_BUCKET):  
 client.make\_bucket(MINIO\_BUCKET)  
 logger.info(f"Created bucket: {MINIO\_BUCKET}")  
 else:  
 logger.info(f"Bucket exists: {MINIO\_BUCKET}")  
  
 if args.clear\_first and not args.dry\_run:  
 print("\n[!] Clearing existing bucket contents...")  
 clear\_bucket(client, MINIO\_BUCKET)  
  
 # ── Parse ──────────────────────────────────────────────────────  
 print("\n[2/4] Parsing historical data...")  
 data\_path = Path(args.data\_file)  
 if not data\_path.exists():  
 print(f"❌ File not found: {data\_path}")  
 sys.exit(1)  
  
 # Count lines for progress bar  
 with open(data\_path, "r") as f:  
 total\_lines = sum(1 for \_ in f)  
 logger.info(f"Total lines: {total\_lines:,}")  
  
 # Group records by (year, month, day) using updated\_timestamp  
 day\_buckets = defaultdict(list) # key: (year, month, day)  
 parsed = skipped = 0  
  
 with open(data\_path, "r") as f:  
 for line in tqdm(f, total=total\_lines, desc="Parsing", unit=" lines"):  
 record = parse\_line(line)  
 if record is None or record["updated\_timestamp"] is None:  
 skipped += 1  
 continue  
 # Only keep records with sensor values  
 if record["temperature"] is None:  
 skipped += 1  
 continue  
 try:  
 ts = datetime.fromisoformat(record["updated\_timestamp"])  
 key = (ts.year, ts.month, ts.day)  
 day\_buckets[key].append(record)  
 parsed += 1  
 except ValueError:  
 skipped += 1  
  
 print(f"\n ✅ Parsed : {parsed:,} rows with sensor data")  
 print(f" ⏭️ Skipped : {skipped:,} rows (no sensor values or parse error)")  
 print(f" 📅 Days : {len(day\_buckets)} unique day partitions")  
  
 if parsed == 0:  
 print("❌ No data parsed.")  
 sys.exit(1)  
  
 # ── Compact + Upload ───────────────────────────────────────────  
 print("\n[3/4] Compacting and uploading (1 file per day)...")  
  
 stats = {"files": 0, "rows": 0, "bytes": 0}  
  
 for (year, month, day), records in tqdm(  
 sorted(day\_buckets.items()),  
 desc="Uploading",  
 unit=" days",  
 ):  
 if args.dry\_run:  
 motes = len({r["mote\_id"] for r in records})  
 logger.info(  
 f" [DRY-RUN] year={year}/month={month:02d}/day={day:02d}/data.parquet "  
 f"— {len(records):,} rows, {motes} motes"  
 )  
 stats["files"] += 1  
 stats["rows"] += len(records)  
 continue  
  
 try:  
 size = upload\_day\_parquet(client, MINIO\_BUCKET, year, month, day, records)  
 if size > 0:  
 stats["files"] += 1  
 stats["rows"] += len(records)  
 stats["bytes"] += size  
 except Exception as e:  
 logger.error(f"Failed year={year}/month={month:02d}/day={day:02d}: {e}")  
  
 # ── Summary ────────────────────────────────────────────────────  
 print("\n[4/4] Summary")  
 print("=" \* 60)  
 print(f" Rows parsed : {parsed:,}")  
 print(f" Day partitions : {stats['files']}")  
 print(f" Rows uploaded : {stats['rows']:,}")  
 print(f" Data uploaded : {stats['bytes']/1024/1024:.2f} MB")  
 print("=" \* 60)  
  
 if args.dry\_run:  
 print("\n⚠️ DRY-RUN — no changes made. Remove --dry-run to execute.")  
 else:  
 print("\n✅ Done! Next step:")  
 print(" python scripts/train\_model.py --source minio")  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/ml/diagnose\_model.py

import pickle, json, pandas as pd  
from pathlib import Path  
from datetime import datetime  
  
reg = json.load(open('src/app/ml/models/model\_registry.json'))  
print('Full registry:')  
print(json.dumps(reg, indent=2))  
  
# Find the model path from whatever structure exists  
model\_path = None  
  
# Structure 1: reg['models'][version]['path']  
if 'models' in reg:  
 models = reg['models']  
 latest\_key = reg.get('latest')  
 print('Latest key:', latest\_key)  
 if latest\_key and latest\_key in models:  
 model\_path = models[latest\_key]['path']  
 else:  
 # Get last model  
 last = sorted(models.keys())[-1]  
 model\_path = models[last]['path']  
 print('Using last model:', last)  
  
# Structure 2: reg[version]['path']  
elif any('path' in v for v in reg.values() if isinstance(v, dict)):  
 for k, v in sorted(reg.items()):  
 if isinstance(v, dict) and 'path' in v:  
 model\_path = v['path']  
 print('Found model path:', model\_path)  
  
print('Model path:', model\_path)  
  
if not model\_path:  
 print('ERROR: Could not find model path in registry')  
 exit(1)  
  
# Try both relative and absolute  
p = Path(model\_path)  
if not p.exists():  
 p = Path('src/app/ml/models') / p.name  
 print('Trying relative path:', p)  
  
if not p.exists():  
 print('ERROR: Model file not found at', p)  
 # List all pkl files  
 print('Available pkl files:')  
 for f in Path('src/app/ml/models').glob('\*.pkl'):  
 print(' ', f)  
 exit(1)  
  
print('Loading model from:', p)  
with open(p, 'rb') as f:  
 artifact = pickle.load(f)  
  
print('Artifact type:', type(artifact))  
if isinstance(artifact, dict):  
 print('Artifact keys:', list(artifact.keys()))  
 pipeline = artifact['pipeline']  
 print('Metrics:', json.dumps(artifact.get('metrics'), indent=2))  
else:  
 pipeline = artifact  
  
now = datetime.utcnow()  
test\_data = pd.DataFrame([  
 {'temperature': 22.5, 'humidity': 55.0, 'light': 300.0, 'voltage': 2.9, 'hour': now.hour, 'day\_of\_week': now.weekday()},  
 {'temperature': 20.0, 'humidity': 60.0, 'light': 200.0, 'voltage': 3.0, 'hour': now.hour, 'day\_of\_week': now.weekday()},  
 {'temperature': 25.0, 'humidity': 50.0, 'light': 400.0, 'voltage': 2.8, 'hour': now.hour, 'day\_of\_week': now.weekday()},  
 {'temperature': 0.0, 'humidity': 0.0, 'light': 0.0, 'voltage': 0.0, 'hour': now.hour, 'day\_of\_week': now.weekday()},  
 {'temperature': 95.0, 'humidity': 2.0, 'light': 0.0, 'voltage': 0.1, 'hour': now.hour, 'day\_of\_week': now.weekday()},  
])  
  
preds = pipeline.predict(test\_data)  
scores = pipeline.decision\_function(test\_data)  
  
print('\n--- Predictions ---')  
labels = ['normal\_22.5', 'normal\_20.0', 'normal\_25.0', 'ZEROS', 'EXTREME']  
for label, pred, score in zip(labels, preds, scores):  
 flag = 'ANOMALY ❌' if pred == -1 else 'normal ✅'  
 print(f' {label:15s} pred={pred:+d} score={score:+.4f} -> {flag}')

## scripts/ml/diagnose\_registry.py

import pickle, json, pandas as pd  
from pathlib import Path  
from datetime import datetime  
  
reg = json.load(open('src/app/ml/models/model\_registry.json'))  
print('Full registry:')  
print(json.dumps(reg, indent=2))

## scripts/remap\_timestamps.py

"""Remap updated\_timestamp fields in historical and incremental data files.  
  
Strategy  
--------  
Historical 80%  
 - Find the max updated\_timestamp in the file → call it hist\_last\_ts  
 - Compute offset = yesterday - hist\_last\_ts.date()  
 - Add that offset to EVERY updated\_timestamp in the file  
 - Result: last historical record lands on yesterday  
  
Incremental 20%  
 - Collect all unique ORIGINAL dates (parts[0], e.g. 2004-03-21)  
 - Sort them → map unique\_dates[0] → today, unique\_dates[1] → today+1, …  
 - For each line: keep the time-of-day, swap only the date  
 - Result: each original calendar day becomes one real calendar day from today  
  
Analogy: Historical is like a printed book — shift all its page-dates by the  
same number of days so the last page says "yesterday". Incremental is like a  
live diary — each chapter (original date) gets a new publication date starting  
from today.  
  
Usage  
-----  
 python scripts/remap\_timestamps.py # remap both files  
 python scripts/remap\_timestamps.py --hist-only  
 python scripts/remap\_timestamps.py --incr-only  
 python scripts/remap\_timestamps.py --dry-run # preview, no writes  
"""  
  
import sys  
import os  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import argparse  
import shutil  
from datetime import date, datetime, timedelta  
from pathlib import Path  
  
  
# ── helpers ──────────────────────────────────────────────────────────────────  
  
def \_last\_field(parts: list) -> str | None:  
 """Return updated\_timestamp (last column) if the line has valid data."""  
 if len(parts) in (4, 9):  
 return parts[-1]  
 return None  
  
  
def \_replace\_last\_field(line: str, new\_value: str) -> str:  
 """Swap the last whitespace-separated token in a line, keeping all others."""  
 parts = line.rstrip("\r\n").rsplit(None, 1)  
 if len(parts) == 2:  
 # Preserve original spacing prefix  
 prefix = parts[0]  
 return prefix + " " + new\_value + "\n"  
 return line # malformed — leave untouched  
  
  
def \_parse\_ts(ts\_str: str) -> datetime | None:  
 """Parse ISO timestamp string, tolerating Z suffix."""  
 try:  
 return datetime.fromisoformat(ts\_str.replace("Z", "+00:00").split("+")[0])  
 except Exception:  
 return None  
  
  
# ── scan passes ──────────────────────────────────────────────────────────────  
  
def \_find\_hist\_max\_date(path: Path) -> date | None:  
 """Single-pass scan to find the latest updated\_timestamp date in the file."""  
 max\_date = None  
 with open(path, "r", encoding="utf-8", errors="replace") as f:  
 for line in f:  
 parts = line.split()  
 ts\_str = \_last\_field(parts)  
 if not ts\_str:  
 continue  
 ts = \_parse\_ts(ts\_str)  
 if ts and (max\_date is None or ts.date() > max\_date):  
 max\_date = ts.date()  
 return max\_date  
  
  
def \_find\_incr\_orig\_dates(path: Path) -> list:  
 """Collect unique original dates (parts[0]) from incremental file, sorted."""  
 dates = set()  
 with open(path, "r", encoding="utf-8", errors="replace") as f:  
 for line in f:  
 parts = line.split()  
 if len(parts) >= 4:  
 try:  
 dates.add(date.fromisoformat(parts[0]))  
 except ValueError:  
 pass  
 return sorted(dates)  
  
  
# ── remap functions ───────────────────────────────────────────────────────────  
  
def remap\_historical(path: Path, dry\_run: bool = False) -> dict:  
 """Shift all updated\_timestamps in historical file so max date = yesterday."""  
 print(f"\n[Historical] Scanning {path.name} for max updated\_timestamp…")  
 hist\_max = \_find\_hist\_max\_date(path)  
 if hist\_max is None:  
 print(" ❌ Could not find any valid timestamps.")  
 return {}  
  
 yesterday = date.today() - timedelta(days=1)  
 offset = timedelta(days=(yesterday - hist\_max).days)  
  
 print(f" Max date found : {hist\_max}")  
 print(f" Yesterday : {yesterday}")  
 print(f" Offset applied : {'+' if offset.days >= 0 else ''}{offset.days} days")  
  
 if dry\_run:  
 print(" DRY RUN — no file written.")  
 return {"max\_before": str(hist\_max), "max\_after": str(yesterday), "offset\_days": offset.days}  
  
 # Backup  
 backup = path.with\_suffix(".txt.bak")  
 shutil.copy2(path, backup)  
 print(f" Backup written : {backup.name}")  
  
 # Stream-rewrite  
 tmp = path.with\_suffix(".txt.tmp")  
 changed = skipped = 0  
 with open(path, "r", encoding="utf-8", errors="replace") as src, \  
 open(tmp, "w", encoding="utf-8") as dst:  
 for line in src:  
 parts = line.split()  
 ts\_str = \_last\_field(parts)  
 if ts\_str:  
 ts = \_parse\_ts(ts\_str)  
 if ts:  
 new\_ts = (ts + offset).isoformat(timespec="microseconds")  
 # isoformat uses +00:00 suffix if tz-aware; strip it for consistency  
 new\_ts = new\_ts.split("+")[0]  
 dst.write(\_replace\_last\_field(line, new\_ts))  
 changed += 1  
 continue  
 dst.write(line)  
 skipped += 1  
  
 tmp.replace(path)  
 print(f" Lines remapped : {changed:,} (skipped {skipped:,} unparseable)")  
 print(f" ✅ {path.name} updated.")  
 return {"max\_before": str(hist\_max), "max\_after": str(yesterday),  
 "offset\_days": offset.days, "changed": changed}  
  
  
def remap\_incremental(path: Path, dry\_run: bool = False) -> dict:  
 """Remap each unique original date in incremental file → today + N days."""  
 print(f"\n[Incremental] Scanning {path.name} for unique original dates…")  
 orig\_dates = \_find\_incr\_orig\_dates(path)  
 if not orig\_dates:  
 print(" ❌ No valid dates found.")  
 return {}  
  
 today = date.today()  
 date\_map = {d: today + timedelta(days=i) for i, d in enumerate(orig\_dates)}  
  
 print(f" Unique original dates : {len(orig\_dates)}")  
 print(f" Mapping preview:")  
 for orig, new in list(date\_map.items())[:3]:  
 print(f" {orig} → {new}")  
 if len(date\_map) > 3:  
 last\_orig, last\_new = list(date\_map.items())[-1]  
 print(f" …")  
 print(f" {last\_orig} → {last\_new} (last)")  
  
 if dry\_run:  
 print(" DRY RUN — no file written.")  
 return {  
 "unique\_dates": len(orig\_dates),  
 "first\_day": str(today),  
 "last\_day": str(today + timedelta(days=len(orig\_dates) - 1)),  
 }  
  
 # Backup  
 backup = path.with\_suffix(".txt.bak")  
 shutil.copy2(path, backup)  
 print(f" Backup written : {backup.name}")  
  
 # Stream-rewrite  
 tmp = path.with\_suffix(".txt.tmp")  
 changed = skipped = 0  
 with open(path, "r", encoding="utf-8", errors="replace") as src, \  
 open(tmp, "w", encoding="utf-8") as dst:  
 for line in src:  
 parts = line.split()  
 ts\_str = \_last\_field(parts)  
 if ts\_str and len(parts) >= 4:  
 try:  
 orig\_date = date.fromisoformat(parts[0])  
 new\_date = date\_map.get(orig\_date)  
 ts = \_parse\_ts(ts\_str)  
 if new\_date and ts:  
 # Keep the exact time-of-day, swap only the date  
 new\_ts = datetime.combine(new\_date, ts.time()).isoformat(timespec="microseconds")  
 dst.write(\_replace\_last\_field(line, new\_ts))  
 changed += 1  
 continue  
 except (ValueError, KeyError):  
 pass  
 dst.write(line)  
 skipped += 1  
  
 tmp.replace(path)  
 print(f" Lines remapped : {changed:,} (skipped {skipped:,} unparseable)")  
 print(f" ✅ {path.name} updated.")  
 return {  
 "unique\_dates": len(orig\_dates),  
 "first\_day": str(today),  
 "last\_day": str(today + timedelta(days=len(orig\_dates) - 1)),  
 "changed": changed,  
 }  
  
  
# ── main ─────────────────────────────────────────────────────────────────────  
  
def main():  
 parser = argparse.ArgumentParser(description="Remap updated\_timestamps in SIEIS data files")  
 parser.add\_argument("--hist-only", action="store\_true", help="Remap historical file only")  
 parser.add\_argument("--incr-only", action="store\_true", help="Remap incremental file only")  
 parser.add\_argument("--dry-run", action="store\_true", help="Preview remapping without writing")  
 parser.add\_argument(  
 "--hist-file", default="data/processed/historical\_data.txt",  
 help="Path to historical file"  
 )  
 parser.add\_argument(  
 "--incr-file", default="data/processed/incremental\_data.txt",  
 help="Path to incremental file"  
 )  
 args = parser.parse\_args()  
  
 do\_hist = not args.incr\_only  
 do\_incr = not args.hist\_only  
  
 hist\_path = Path(args.hist\_file)  
 incr\_path = Path(args.incr\_file)  
  
 print("=" \* 60)  
 print("SIEIS Timestamp Remap")  
 print(f"Today : {date.today()}")  
 print(f"Yesterday : {date.today() - timedelta(days=1)}")  
 print(f"Dry run : {args.dry\_run}")  
 print("=" \* 60)  
  
 results = {}  
  
 if do\_hist:  
 if not hist\_path.exists():  
 print(f"\n❌ Historical file not found: {hist\_path}")  
 else:  
 results["historical"] = remap\_historical(hist\_path, dry\_run=args.dry\_run)  
  
 if do\_incr:  
 if not incr\_path.exists():  
 print(f"\n❌ Incremental file not found: {incr\_path}")  
 else:  
 results["incremental"] = remap\_incremental(incr\_path, dry\_run=args.dry\_run)  
  
 # ── summary ──────────────────────────────────────────────────────────────  
 print("\n" + "=" \* 60)  
 print("SUMMARY")  
 print("=" \* 60)  
  
 if "historical" in results and results["historical"]:  
 r = results["historical"]  
 print(f" Historical : {r.get('max\_before')} → {r.get('max\_after')} "  
 f"(+{r.get('offset\_days')} days) {r.get('changed', 'n/a'):,} lines")  
  
 if "incremental" in results and results["incremental"]:  
 r = results["incremental"]  
 print(f" Incremental: {r.get('unique\_dates')} unique dates "  
 f"→ {r.get('first\_day')} … {r.get('last\_day')}")  
  
 if not args.dry\_run:  
 print()  
 print("Next steps:")  
 print(" 1. Load historical to MinIO only:")  
 print(" python scripts/load\_historical\_data.py --minio-only")  
 print(" 2. Start Docker pipeline for incremental stream:")  
 print(" docker compose up -d")  
 print("=" \* 60)  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/retrain\_model.py

"""Retrain the SIEIS anomaly detection model with fresh data.  
  
Usage:  
 python scripts/retrain\_model.py [--days 30] [--source local|minio]  
  
This script is for incremental retraining — run it after new data arrives.  
Like refreshing a spam filter after the spam landscape changes.  
"""  
  
import sys  
import os  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import argparse  
import json  
import logging  
  
logging.basicConfig(level=logging.INFO, format="%(asctime)s [%(levelname)s] %(message)s")  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def main():  
 parser = argparse.ArgumentParser(description="Retrain SIEIS anomaly detection model")  
 parser.add\_argument("--days", type=int, default=30, help="Days of recent data to use")  
 parser.add\_argument(  
 "--source",  
 choices=["local", "minio", "influxdb"],  
 default="local",  
 help="Data source for retraining",  
 )  
 parser.add\_argument("--contamination", type=float, default=0.05)  
 args = parser.parse\_args()  
  
 from src.app import config  
 from src.app.ml.detector import \_load\_registry, train\_anomaly\_detector, save\_model  
 from src.app.ml.preprocessing.data\_prep import (  
 load\_from\_local\_file,  
 load\_parquet\_from\_minio,  
 prepare\_features,  
 )  
  
 print("=" \* 60)  
 print("SIEIS — Incremental Model Retraining")  
 print(f"Source: {args.source} | Days: {args.days}")  
 print("=" \* 60)  
  
 # Show current registry state  
 registry = \_load\_registry()  
 print(f"\nCurrent registry: {len(registry.get('models', []))} model(s)")  
 if registry.get("latest"):  
 print(f"Current latest: {registry['latest']}")  
  
 # Load data  
 print(f"\n[1/4] Loading data...")  
 if args.source == "minio":  
 df = load\_parquet\_from\_minio(max\_files=50)  
 if df.empty:  
 print("⚠️ No MinIO data, falling back to local")  
 args.source = "local"  
  
 if args.source == "influxdb":  
 print("Loading recent data from InfluxDB...")  
 try:  
 from influxdb\_client import InfluxDBClient  
 client = InfluxDBClient(  
 url=config.INFLUX\_URL, token=config.INFLUX\_TOKEN, org=config.INFLUX\_ORG  
 )  
 query\_api = client.query\_api()  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: -{args.days}d)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> pivot(rowKey:["\_time","mote\_id"], columnKey: ["\_field"], valueColumn: "\_value")  
 |> limit(n: 200000)  
"""  
 import pandas as pd  
 tables = query\_api.query\_data\_frame(flux, org=config.INFLUX\_ORG)  
 client.close()  
 if isinstance(tables, list):  
 df = pd.concat(tables, ignore\_index=True)  
 else:  
 df = tables  
 # Rename \_time to timestamp  
 if "\_time" in df.columns:  
 df = df.rename(columns={"\_time": "timestamp"})  
 print(f" Loaded {len(df):,} rows from InfluxDB")  
 except Exception as e:  
 print(f"⚠️ InfluxDB load failed ({e}), falling back to local")  
 args.source = "local"  
  
 if args.source == "local":  
 hist\_path = config.DATA\_DIR / "processed" / "historical\_data.txt"  
 if not hist\_path.exists():  
 print(f"❌ historical\_data.txt not found at {hist\_path}")  
 sys.exit(1)  
 df = load\_from\_local\_file(str(hist\_path), max\_rows=200\_000)  
  
 print(f" Loaded {len(df):,} rows")  
  
 # Prepare features  
 print("\n[2/4] Preparing features...")  
 X, mote\_ids = prepare\_features(df)  
 print(f" Feature matrix: {X.shape}")  
  
 # Train  
 print(f"\n[3/4] Training new model version...")  
 pipeline, metrics = train\_anomaly\_detector(X, contamination=args.contamination)  
 print(f" Anomalies: {metrics['n\_anomalies\_detected']:,} ({metrics['anomaly\_ratio']:.1%})")  
  
 # Save with retrain tag  
 print("\n[4/4] Saving new model version...")  
 filename = save\_model(pipeline, metrics, tag="retrain")  
  
 print("\n" + "=" \* 60)  
 print("RETRAINING COMPLETE")  
 print("=" \* 60)  
 print(f" New model: {filename}")  
 print(f" Reload API: curl -X POST http://localhost:8000/api/v1/ml/model/reload")  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/run\_dashboard.py

"""Launch the SIEIS Streamlit dashboard.  
  
Usage:  
 python scripts/run\_dashboard.py  
"""  
  
import os  
import sys  
import subprocess  
  
# Ensure we're in the project root  
project\_root = os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_)))  
os.chdir(project\_root)  
  
dashboard\_path = os.path.join(project\_root, "src", "app", "dashboard", "app.py")  
  
print("🚀 Starting SIEIS Dashboard...")  
print(f" Dashboard path: {dashboard\_path}")  
print(f" URL: http://localhost:8501")  
print(" Press Ctrl+C to stop\n")  
  
subprocess.run([  
 sys.executable, "-m", "streamlit", "run",  
 dashboard\_path,  
 "--server.port", "8501",  
 "--server.address", "0.0.0.0",  
 "--browser.gatherUsageStats", "false",  
], check=True)

## scripts/simple\_verify.py

"""Simple verification: Check if 80% bulk load succeeded."""  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import pandas as pd  
from src.app.config import INFLUX\_URL, INFLUX\_TOKEN, INFLUX\_ORG, INFLUX\_BUCKET, DATA\_DIR  
DATA\_PATH = DATA\_DIR / "processed" / "historical\_data.txt"  
from influxdb\_client import InfluxDBClient  
  
print("🔍 SIMPLE 80% DATA LOAD VERIFICATION")  
print("="\*50)  
  
# Expected 80% counts  
df = pd.read\_csv(DATA\_PATH, sep=r'\s+', header=None,   
 names=['date', 'time', 'epoch', 'moteid', 'temperature', 'humidity', 'light', 'voltage'],  
 na\_values=['?'])  
df['timestamp'] = pd.to\_datetime(df['date'] + ' ' + df['time'], format='%Y-%m-%d %H:%M:%S.%f', errors='coerce')  
df = df.dropna(subset=['timestamp', 'moteid', 'temperature', 'humidity'])  
df = df.sort\_values('timestamp')  
  
min\_ts = df['timestamp'].min()  
max\_ts = df['timestamp'].max()  
cutoff\_ts = min\_ts + (max\_ts - min\_ts) \* 0.80  
df\_80 = df[df['timestamp'] <= cutoff\_ts]  
  
expected\_records = len(df\_80)  
expected\_points = expected\_records \* 4 # 4 fields per record  
  
print(f"Expected from CSV (80%):")  
print(f" Records: {expected\_records:,}")  
print(f" Points: {expected\_points:,}")  
print(f" Date range: {min\_ts.date()} to {cutoff\_ts.date()}")  
  
# Check InfluxDB  
client = InfluxDBClient(url=INFLUX\_URL, token=INFLUX\_TOKEN, org=INFLUX\_ORG, timeout=60000)  
query\_api = client.query\_api()  
  
# Simple count query  
result = query\_api.query(f'from(bucket: "{INFLUX\_BUCKET}") |> range(start: 2004-01-01, stop: 2005-01-01) |> filter(fn: (r) => r.\_measurement == "sensor\_reading") |> count()')  
total\_points = sum(record.get\_value() for table in result for record in table.records)  
  
print(f"\nActual in InfluxDB:")  
print(f" Points: {total\_points:,}")  
  
# Check success  
success\_rate = (total\_points / expected\_points) \* 100 if expected\_points > 0 else 0  
print(f"\nVerification:")  
print(f" Success rate: {success\_rate:.1f}%")  
  
if success\_rate >= 95:  
 print(" Status: ✅ PASSED - 80% bulk load successful!")  
elif success\_rate >= 80:  
 print(" Status: ⚠️ PARTIAL - Most data loaded")  
else:  
 print(" Status: ❌ FAILED - Data load incomplete")  
  
client.close()

## scripts/split\_dataset.py

"""Split the full sensor dataset into 80% historical and 20% incremental.  
  
The source file is data/processed/realtime\_data.txt (full dataset with  
remapped 2026 timestamps). Lines are split in chronological order so the  
80% block represents the past and the 20% block represents "new" data.  
  
Usage:  
 python scripts/split\_dataset.py  
 python scripts/split\_dataset.py --split 0.8  
 python scripts/split\_dataset.py --source data/processed/realtime\_data.txt  
 python scripts/split\_dataset.py --dry-run  
  
Analogy: Think of the dataset like a stack of dated newspapers. We keep  
the oldest 80% as the archive (historical), and the newest 20% as the  
fresh pile that arrives incrementally.  
"""  
  
import sys  
import os  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_))))  
  
import argparse  
import json  
import shutil  
from datetime import datetime  
from pathlib import Path  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
  
def count\_lines(filepath: Path) -> int:  
 """Count lines in a file efficiently without loading it all into memory."""  
 count = 0  
 with open(filepath, "r", encoding="utf-8", errors="replace") as f:  
 for \_ in f:  
 count += 1  
 return count  
  
  
def split\_dataset(  
 source: Path,  
 historical\_out: Path,  
 incremental\_out: Path,  
 split\_ratio: float = 0.8,  
 dry\_run: bool = False,  
):  
 """Split source file into historical (split\_ratio) and incremental (1-split\_ratio).  
  
 Args:  
 source: Input file (full dataset with remapped timestamps)  
 historical\_out: Output file for first split\_ratio of lines  
 incremental\_out: Output file for remaining lines  
 split\_ratio: Fraction for historical split (default 0.8 = 80%)  
 dry\_run: If True, only count and report without writing  
 """  
 print("=" \* 65)  
 print("SIEIS Dataset Split")  
 print(f"Source : {source}")  
 print(f"Split : {split\_ratio:.0%} historical / {1-split\_ratio:.0%} incremental")  
 print(f"Dry run: {dry\_run}")  
 print("=" \* 65)  
  
 # ── Step 1: count total lines ──────────────────────────────────────────  
 print("\n[1/3] Counting lines in source file...")  
 total = count\_lines(source)  
 historical\_count = int(total \* split\_ratio)  
 incremental\_count = total - historical\_count  
  
 print(f" Total lines : {total:>12,}")  
 print(f" Historical (80%) : {historical\_count:>12,}")  
 print(f" Incremental (20%): {incremental\_count:>12,}")  
  
 if dry\_run:  
 print("\n✅ Dry run complete — no files written.")  
 return historical\_count, incremental\_count  
  
 # ── Step 2: backup existing files if present ───────────────────────────  
 print("\n[2/3] Backing up existing split files...")  
 for path in (historical\_out, incremental\_out):  
 if path.exists():  
 backup = path.with\_suffix(".txt.bak")  
 shutil.copy2(path, backup)  
 print(f" Backed up: {path.name} → {backup.name}")  
  
 # ── Step 3: stream-write the split ────────────────────────────────────  
 print("\n[3/3] Writing split files...")  
  
 written\_hist = 0  
 written\_incr = 0  
 start = datetime.now()  
  
 with open(source, "r", encoding="utf-8", errors="replace") as src, \  
 open(historical\_out, "w", encoding="utf-8") as hist\_f, \  
 open(incremental\_out, "w", encoding="utf-8") as incr\_f:  
  
 for line\_num, line in enumerate(src, 1):  
 if line\_num <= historical\_count:  
 hist\_f.write(line)  
 written\_hist += 1  
 else:  
 incr\_f.write(line)  
 written\_incr += 1  
  
 # Print progress every 10%  
 if line\_num % max(1, total // 10) == 0:  
 pct = line\_num / total \* 100  
 elapsed = (datetime.now() - start).total\_seconds()  
 rate = line\_num / elapsed if elapsed > 0 else 0  
 print(f" {pct:5.0f}% — {line\_num:,}/{total:,} lines ({rate:,.0f} lines/sec)")  
  
 elapsed = (datetime.now() - start).total\_seconds()  
  
 # ── Reset checkpoint so load\_historical\_data starts fresh ─────────────  
 checkpoint\_path = Path("data/.checkpoint\_historical.json")  
 checkpoint\_path.parent.mkdir(parents=True, exist\_ok=True)  
 with open(checkpoint\_path, "w") as f:  
 json.dump({  
 "last\_line": 0,  
 "timestamp": datetime.now().isoformat(),  
 "stats": {  
 "total\_read": 0,  
 "influx\_written": 0,  
 "minio\_written": 0,  
 "skipped": 0,  
 "errors": 0,  
 },  
 "note": f"Reset by split\_dataset.py — {split\_ratio:.0%}/{1-split\_ratio:.0%} split",  
 }, f, indent=2)  
 print(f"\n ✅ Checkpoint reset: {checkpoint\_path}")  
  
 # ── Summary ───────────────────────────────────────────────────────────  
 hist\_size\_mb = historical\_out.stat().st\_size / (1024 \* 1024)  
 incr\_size\_mb = incremental\_out.stat().st\_size / (1024 \* 1024)  
  
 print("\n" + "=" \* 65)  
 print("SPLIT COMPLETE")  
 print("=" \* 65)  
 print(f" Time elapsed : {elapsed:.1f}s")  
 print(f" historical\_data.txt : {written\_hist:>10,} lines ({hist\_size\_mb:.1f} MB)")  
 print(f" incremental\_data.txt: {written\_incr:>10,} lines ({incr\_size\_mb:.1f} MB)")  
 print()  
 print("Next steps:")  
 print(" 1. Load historical data into InfluxDB + MinIO:")  
 print(" python scripts/load\_historical\_data.py")  
 print(" 2. Start Docker pipeline (streams incremental data):")  
 print(" docker compose up -d")  
 print(" 3. Verify data is flowing:")  
 print(" python scripts/verify\_influxDb.py")  
 print(" python scripts/verify\_minio\_storage.py")  
 print(" 4. Train the ML model:")  
 print(" python scripts/train\_model.py")  
 print("=" \* 65)  
  
 return written\_hist, written\_incr  
  
  
def main():  
 parser = argparse.ArgumentParser(description="Split SIEIS dataset into historical/incremental")  
 parser.add\_argument(  
 "--source",  
 default="data/processed/realtime\_data.txt",  
 help="Source file (default: data/processed/realtime\_data.txt)",  
 )  
 parser.add\_argument(  
 "--historical-out",  
 default="data/processed/historical\_data.txt",  
 help="Output path for historical split (default: data/processed/historical\_data.txt)",  
 )  
 parser.add\_argument(  
 "--incremental-out",  
 default="data/processed/incremental\_data.txt",  
 help="Output path for incremental split (default: data/processed/incremental\_data.txt)",  
 )  
 parser.add\_argument(  
 "--split",  
 type=float,  
 default=0.8,  
 metavar="RATIO",  
 help="Fraction of data for historical split (default: 0.8 = 80%%)",  
 )  
 parser.add\_argument(  
 "--dry-run",  
 action="store\_true",  
 help="Count lines and report only — do not write files",  
 )  
 args = parser.parse\_args()  
  
 source = Path(args.source)  
 if not source.exists():  
 print(f"❌ Source file not found: {source}")  
 sys.exit(1)  
  
 if not (0.0 < args.split < 1.0):  
 print(f"❌ --split must be between 0 and 1 (got {args.split})")  
 sys.exit(1)  
  
 split\_dataset(  
 source=source,  
 historical\_out=Path(args.historical\_out),  
 incremental\_out=Path(args.incremental\_out),  
 split\_ratio=args.split,  
 dry\_run=args.dry\_run,  
 )  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/train\_model.py

"""Train the SIEIS anomaly detection model.  
  
Usage:  
 python scripts/train\_model.py [--source local|minio] [--max-rows 500000]  
  
Steps:  
1. Load data from MinIO (Parquet) or local file  
2. Prepare features (clean, engineer time features)  
3. Train Isolation Forest  
4. Save model artifact + update registry  
5. Auto-reload API + test prediction  
"""  
  
import sys  
import os  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import argparse  
import json  
import logging  
import requests  
from pathlib import Path  
  
logging.basicConfig(level=logging.INFO, format="%(asctime)s [%(levelname)s] %(message)s")  
logger = logging.getLogger(\_\_name\_\_)  
  
# API URL — try localhost first, fallback to container name  
API\_URLS = [  
 "http://localhost:8000",  
 "http://sieis-api:8000",  
]  
  
  
def get\_api\_url():  
 """Find which API URL is reachable."""  
 for url in API\_URLS:  
 try:  
 r = requests.get(f"{url}/health", timeout=3)  
 if r.status\_code == 200:  
 return url  
 except Exception:  
 continue  
 return None  
  
  
def fix\_registry\_paths(registry\_path: Path):  
 """Fix Windows absolute paths in registry to relative paths for container compatibility."""  
 if not registry\_path.exists():  
 return  
  
 with open(registry\_path, "r") as f:  
 registry = json.load(f)  
  
 changed = False  
 for key, info in registry.items():  
 if isinstance(info, dict) and "path" in info:  
 p = info["path"]  
 filename = Path(p).name  
 relative = f"src/app/ml/models/{filename}"  
 if info["path"] != relative:  
 info["path"] = relative  
 changed = True  
 logger.info(f"Fixed path for {key}: {p} → {relative}")  
  
 if changed:  
 with open(registry\_path, "w") as f:  
 json.dump(registry, f, indent=2)  
 print(" ✅ Registry paths normalized for container compatibility")  
  
  
def reload\_api\_model(api\_url: str):  
 """Tell the API to reload the latest model from disk."""  
 try:  
 r = requests.post(f"{api\_url}/api/v1/ml/model/reload", timeout=10)  
 if r.status\_code == 200:  
 print(f" ✅ API model reloaded: {r.json()}")  
 else:  
 print(f" ⚠️ API reload returned {r.status\_code}: {r.text}")  
 except Exception as e:  
 print(f" ⚠️ Could not reload API model: {e}")  
  
  
def test\_prediction(api\_url: str):  
 """Send a test prediction to verify the model is working end-to-end."""  
 payload = {  
 "temperature": 22.5,  
 "humidity": 55.0,  
 "light": 300,  
 "voltage": 2.9  
 }  
 try:  
 r = requests.post(  
 f"{api\_url}/api/v1/ml/predict/anomaly",  
 json=payload,  
 timeout=10  
 )  
 if r.status\_code == 200:  
 result = r.json()  
 is\_anomaly = result.get("is\_anomaly", "unknown")  
 score = result.get("anomaly\_score", "unknown")  
 print(f" ✅ Test prediction OK — is\_anomaly: {is\_anomaly}, score: {score}")  
 else:  
 print(f" ⚠️ Prediction returned {r.status\_code}: {r.text}")  
 except Exception as e:  
 print(f" ⚠️ Could not test prediction: {e}")  
  
  
def main():  
 parser = argparse.ArgumentParser(description="Train SIEIS anomaly detection model")  
 parser.add\_argument(  
 "--source",  
 choices=["local", "minio"],  
 default="minio",  
 help="Data source: 'local' (historical\_data.txt) or 'minio' (Parquet files)",  
 )  
 parser.add\_argument("--max-rows", type=int, default=0, help="Max rows to load (0 = all rows)")  
 parser.add\_argument("--contamination", type=float, default=0.05, help="Expected anomaly fraction")  
 parser.add\_argument("--tag", type=str, default=None, help="Optional tag for model filename")  
 parser.add\_argument("--no-reload", action="store\_true", help="Skip API reload after training")  
 args = parser.parse\_args()  
  
 print("=" \* 60)  
 print("SIEIS — Anomaly Detection Model Training")  
 max\_rows\_label = 'ALL' if args.max\_rows == 0 else f'{args.max\_rows:,}'  
 print(f"Source: {args.source} | Max rows: {max\_rows\_label}")  
 print("=" \* 60)  
  
 from src.app import config  
 from src.app.ml.preprocessing.data\_prep import (  
 load\_from\_local\_file,  
 load\_parquet\_from\_minio,  
 prepare\_features,  
 )  
 from src.app.ml.detector import train\_anomaly\_detector, save\_model  
  
 # ── Step 1: Load data ──────────────────────────────────────────  
 print(f"\n[1/5] Loading data from {args.source}...")  
 if args.source == "minio":  
 df = load\_parquet\_from\_minio(max\_files=0) # 0 = load all files  
 if df.empty:  
 print("⚠️ No data in MinIO. Falling back to local file.")  
 args.source = "local"  
 else:  
 if args.max\_rows > 0 and len(df) > args.max\_rows:  
 df = df.sample(n=args.max\_rows, random\_state=42)  
 print(f" Sampled down to {args.max\_rows:,} rows")  
  
 if args.source == "local":  
 hist\_path = config.DATA\_DIR / "processed" / "historical\_data.txt"  
 if not hist\_path.exists():  
 print(f"❌ historical\_data.txt not found at {hist\_path}")  
 sys.exit(1)  
 df = load\_from\_local\_file(str(hist\_path), max\_rows=args.max\_rows)  
  
 print(f" ✅ Loaded {len(df):,} rows")  
  
 # ── Step 2: Prepare features ───────────────────────────────────  
 print("\n[2/5] Preparing features...")  
 X, mote\_ids = prepare\_features(df)  
 print(f" ✅ Feature matrix: {X.shape} | Features: {list(X.columns)}")  
 print(f" ✅ Unique motes: {len(set(mote\_ids))}")  
  
 if len(X) < 100:  
 print("❌ Too few samples for training (need at least 100)")  
 sys.exit(1)  
  
 # ── Step 3: Train ──────────────────────────────────────────────  
 print(f"\n[3/5] Training Isolation Forest (contamination={args.contamination})...")  
 pipeline, metrics = train\_anomaly\_detector(X, contamination=args.contamination)  
 print(f" ✅ Training complete!")  
 print(f" ✅ Samples: {metrics['n\_samples']:,}")  
 print(f" ✅ Anomalies detected: {metrics['n\_anomalies\_detected']:,} ({metrics['anomaly\_ratio']:.1%})")  
  
 # ── Step 4: Save + fix registry paths ─────────────────────────  
 print("\n[4/5] Saving model...")  
 filename = save\_model(pipeline, metrics, tag=args.tag)  
 print(f" ✅ Model saved: src/app/ml/models/{filename}")  
 fix\_registry\_paths(Path("src/app/ml/models/model\_registry.json"))  
  
 # ── Step 5: Reload API + test prediction ──────────────────────  
 print("\n[5/5] Reloading API & testing prediction...")  
 if args.no\_reload:  
 print(" ⏭️ Skipped (--no-reload flag set)")  
 else:  
 api\_url = get\_api\_url()  
 if api\_url:  
 print(f" API found at: {api\_url}")  
 reload\_api\_model(api\_url)  
 test\_prediction(api\_url)  
 else:  
 print(" ⚠️ API not reachable at localhost:8000 or sieis-api:8000")  
 print(" Run manually: curl -X POST http://localhost:8000/api/v1/ml/model/reload")  
  
 # ── Summary ────────────────────────────────────────────────────  
 print("\n" + "=" \* 60)  
 print("TRAINING COMPLETE")  
 print("=" \* 60)  
 print(f" Model file : src/app/ml/models/{filename}")  
 print(f" Source : {args.source}")  
 print(f" Samples : {metrics['n\_samples']:,}")  
 print(f" Anomaly ratio : {metrics['anomaly\_ratio']:.1%}")  
 print(f" Unique motes : {len(set(mote\_ids))}")  
 print("=" \* 60)  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/validate\_data\_quality.py

"""Validate data quality in InfluxDB and MinIO.  
  
Usage:  
 python scripts/validate\_data\_quality.py  
  
Checks:  
- InfluxDB connectivity and recent data  
- MinIO bucket and Parquet file count  
- Data completeness (missing fields, null rates)  
- Timestamp freshness  
"""  
  
import sys  
import os  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import logging  
from datetime import datetime, timezone  
  
logging.basicConfig(level=logging.INFO, format="%(asctime)s [%(levelname)s] %(message)s")  
logger = logging.getLogger(\_\_name\_\_)  
  
from src.app import config  
  
  
def check\_influxdb() -> bool:  
 """Validate InfluxDB connectivity and recent data presence."""  
 print("\n📊 Checking InfluxDB...")  
 try:  
 from influxdb\_client import InfluxDBClient  
 client = InfluxDBClient(url=config.INFLUX\_URL, token=config.INFLUX\_TOKEN, org=config.INFLUX\_ORG)  
  
 # Ping  
 ok = client.ping()  
 print(f" ✅ Ping: {'OK' if ok else '❌ FAILED'}")  
 if not ok:  
 return False  
  
 # Count recent records  
 query\_api = client.query\_api()  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["\_field"] == "temperature")  
 |> count()  
"""  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
 total = sum(r.get\_value() or 0 for t in tables for r in t.records)  
 print(f" ✅ Records in last 24h: {total:,}")  
  
 # Check mote count  
 flux2 = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> keep(columns: ["mote\_id"])  
 |> distinct(column: "mote\_id")  
 |> count()  
"""  
 tables2 = query\_api.query(flux2, org=config.INFLUX\_ORG)  
 mote\_count = sum(r.get\_value() or 0 for t in tables2 for r in t.records)  
 print(f" ✅ Active motes (24h): {mote\_count}")  
  
 client.close()  
 return total > 0  
  
 except Exception as e:  
 print(f" ❌ InfluxDB check failed: {e}")  
 return False  
  
  
def check\_minio() -> bool:  
 """Validate MinIO connectivity and Parquet files."""  
 print("\n🪣 Checking MinIO...")  
 try:  
 from minio import Minio  
 client = Minio(  
 config.MINIO\_ENDPOINT,  
 access\_key=config.MINIO\_ACCESS\_KEY,  
 secret\_key=config.MINIO\_SECRET\_KEY,  
 secure=config.MINIO\_SECURE,  
 )  
  
 # List buckets  
 buckets = client.list\_buckets()  
 bucket\_names = [b.name for b in buckets]  
 print(f" ✅ Buckets found: {bucket\_names}")  
  
 if config.MINIO\_BUCKET not in bucket\_names:  
 print(f" ❌ Expected bucket '{config.MINIO\_BUCKET}' not found!")  
 return False  
  
 # Count Parquet files  
 objects = list(client.list\_objects(config.MINIO\_BUCKET, recursive=True))  
 parquet\_files = [o for o in objects if o.object\_name.endswith(".parquet")]  
 total\_size\_mb = sum(o.size or 0 for o in parquet\_files) / (1024 \* 1024)  
  
 print(f" ✅ Parquet files: {len(parquet\_files)} ({total\_size\_mb:.1f} MB)")  
  
 if parquet\_files:  
 sample\_names = [o.object\_name for o in parquet\_files[:3]]  
 print(f" 📁 Sample paths: {sample\_names}")  
  
 return len(parquet\_files) > 0  
  
 except Exception as e:  
 print(f" ❌ MinIO check failed: {e}")  
 return False  
  
  
def check\_data\_quality() -> bool:  
 """Check data completeness from local historical file if InfluxDB is empty."""  
 print("\n📋 Checking local data files...")  
 try:  
 import pandas as pd  
  
 hist\_path = config.DATA\_DIR / "processed" / "historical\_data.txt"  
 if not hist\_path.exists():  
 print(f" ⚠️ historical\_data.txt not found at {hist\_path}")  
 return False  
  
 cols = ["date", "time", "epoch", "mote\_id", "temperature", "humidity", "light", "voltage", "updated\_timestamp"]  
 df = pd.read\_csv(hist\_path, sep=r"\s+", names=cols, na\_values=["N/A", "nan", ""], nrows=10000, on\_bad\_lines="skip")  
  
 total = len(df)  
 print(f" ✅ Rows sampled: {total:,}")  
  
 for col in ["temperature", "humidity", "light", "voltage"]:  
 null\_pct = df[col].isna().mean() \* 100  
 status = "✅" if null\_pct < 20 else "⚠️ "  
 print(f" {status} {col}: {null\_pct:.1f}% null")  
  
 mote\_count = df["mote\_id"].nunique()  
 print(f" ✅ Unique motes in sample: {mote\_count}")  
  
 return True  
  
 except Exception as e:  
 print(f" ❌ Data quality check failed: {e}")  
 return False  
  
  
def main():  
 print("=" \* 60)  
 print("SIEIS Data Quality Validation")  
 print(f"Time: {datetime.now(timezone.utc).isoformat()}")  
 print("=" \* 60)  
  
 influx\_ok = check\_influxdb()  
 minio\_ok = check\_minio()  
 local\_ok = check\_data\_quality()  
  
 print("\n" + "=" \* 60)  
 print("SUMMARY")  
 print("=" \* 60)  
 print(f" InfluxDB: {'✅ OK' if influx\_ok else '❌ FAILED or empty'}")  
 print(f" MinIO: {'✅ OK' if minio\_ok else '❌ FAILED or empty'}")  
 print(f" Local: {'✅ OK' if local\_ok else '❌ FAILED'}")  
  
 all\_ok = local\_ok # local is minimum requirement  
 if not all\_ok:  
 print("\n❌ Validation failed — run load\_historical\_data.py first")  
 sys.exit(1)  
 else:  
 print("\n✅ Validation passed — ready for ML training")  
 print(" Next step: python scripts/train\_model.py")  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/verify\_influxDb.py

"""  
Verify InfluxDB has data in the sensor\_data bucket.  
"""  
from influxdb\_client import InfluxDBClient  
import logging  
import sys  
  
# Force UTF-8 output to avoid encoding errors  
if hasattr(sys.stdout, 'reconfigure'):  
 sys.stdout.reconfigure(encoding='utf-8')  
  
logging.basicConfig(level=logging.INFO, format='%(levelname)s: %(message)s')  
logger = logging.getLogger("InfluxDB-Verify")  
  
INFLUXDB\_URL = "http://localhost:8086"  
INFLUXDB\_TOKEN = "my-super-secret-token"  
INFLUXDB\_ORG = "sieis"  
INFLUXDB\_BUCKET = "sensor\_data"  
  
def check\_date\_range(client):  
 """Check the earliest and latest timestamps in the bucket."""  
 query\_api = client.query\_api()  
   
 # Query for earliest record  
 earliest\_query = f'''  
 from(bucket:"{INFLUXDB\_BUCKET}")   
 |> range(start: 0)  
 |> sort(columns: ["\_time"])  
 |> limit(n:1)  
 '''  
   
 # Query for latest record  
 latest\_query = f'''  
 from(bucket:"{INFLUXDB\_BUCKET}")   
 |> range(start: 0)  
 |> sort(columns: ["\_time"], desc: true)  
 |> limit(n:1)  
 '''  
   
 try:  
 logger.info("Checking date range of stored data...")  
   
 earliest\_tables = query\_api.query(earliest\_query)  
 latest\_tables = query\_api.query(latest\_query)  
   
 earliest\_time = None  
 latest\_time = None  
   
 for table in earliest\_tables:  
 if table.records:  
 earliest\_time = table.records[0].get\_time()  
 break  
   
 for table in latest\_tables:  
 if table.records:  
 latest\_time = table.records[0].get\_time()  
 break  
   
 if earliest\_time and latest\_time:  
 logger.info(f"📅 Date Range:")  
 logger.info(f" Earliest: {earliest\_time}")  
 logger.info(f" Latest: {latest\_time}")  
 logger.info(f" Span: {latest\_time - earliest\_time}")  
 return earliest\_time, latest\_time  
 else:  
 logger.warning("⚠️ Could not determine date range (no data found)")  
 return None, None  
   
 except Exception as e:  
 logger.error(f"❌ Error checking date range: {e}")  
 return None, None  
  
def main():  
 logger.info(f"Connecting to InfluxDB at {INFLUXDB\_URL}...")  
   
 try:  
 client = InfluxDBClient(url=INFLUXDB\_URL, token=INFLUXDB\_TOKEN, org=INFLUXDB\_ORG)  
 query\_api = client.query\_api()  
   
 # First check date range  
 earliest, latest = check\_date\_range(client)  
   
 if not earliest:  
 logger.warning("⚠️ No data found in InfluxDB at all!")  
 logger.info("Possible reasons:")  
 logger.info(" 1) Consumer hasn't started yet")  
 logger.info(" 2) Simulator hasn't produced data")  
 logger.info(" 3) Check: docker logs sieis-consumer")  
 client.close()  
 return  
   
 # Query for ALL data first (no measurement filter) to see what's there  
 all\_data\_query = f'''  
 from(bucket:"{INFLUXDB\_BUCKET}")   
 |> range(start: 0)  
 |> limit(n:1000)  
 '''  
   
 logger.info("Querying all data in bucket...")  
 all\_tables = query\_api.query(all\_data\_query)  
   
 # Collect measurements, fields, and other info  
 total\_count = 0  
 mote\_ids = set()  
 fields = set()  
 measurements = set()  
   
 for table in all\_tables:  
 for record in table.records:  
 total\_count += 1  
 mote\_id = record.values.get("mote\_id")  
 field = record.get\_field()  
 measurement = record.get\_measurement()  
   
 if mote\_id:  
 mote\_ids.add(mote\_id)  
 if field:  
 fields.add(field)  
 if measurement:  
 measurements.add(measurement)  
   
 logger.info(f"✅ Total records (sample of 1000): {total\_count:,}")  
 logger.info(f"✅ Measurements found: {measurements}")  
 logger.info(f"✅ Fields found: {fields}")  
   
 # Get unique motes from actual data  
 logger.info(f"✅ Unique motes: {len(mote\_ids)}")  
 if mote\_ids:  
 sample\_motes = sorted(list(mote\_ids))[:10]  
 logger.info(f" Sample: {sample\_motes}")  
   
 # Query for sample recent data  
 query = f'''  
 from(bucket:"{INFLUXDB\_BUCKET}")   
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> limit(n:5)  
 '''  
   
 logger.info("")  
 logger.info("Querying for sample records (last 24h)...")  
 tables = query\_api.query(query)  
   
 record\_count = sum(len(table.records) for table in tables)  
   
 if record\_count > 0:  
 logger.info(f"✅ Found {record\_count} recent records")  
 logger.info("Sample records:")  
 for table in tables[:1]:  
 for record in table.records[:3]:  
 logger.info(f" {record.get\_time()}: mote={record.values.get('mote\_id')} {record.get\_field()}={record.get\_value()}")  
 else:  
 logger.warning("⚠️ No records in last 24h (but older data exists)")  
   
 logger.info("")  
 logger.info("✅ InfluxDB verification complete!")  
 client.close()  
   
 except Exception as e:  
 logger.error(f"❌ Error querying InfluxDB: {e}")  
 import traceback  
 traceback.print\_exc()  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## scripts/verify\_minio\_storage.py

"""  
Verify MinIO storage has expected files.  
List objects in 'sieis-archive' and check if they match today's date.  
"""  
from minio import Minio  
import logging  
from datetime import datetime  
  
# Configure logging  
logging.basicConfig(level=logging.INFO, format='%(asctime)s - %(message)s')  
logger = logging.getLogger("MinIO-Verify")  
  
# Config matches docker-compose  
MINIO\_ENDPOINT = "localhost:9000"  
MINIO\_ACCESS\_KEY = "minioadmin"  
MINIO\_SECRET\_KEY = "minioadmin123"  
BUCKET\_NAME = "sieis-archive"  
  
def main():  
 logger.info(f"Connecting to MinIO at {MINIO\_ENDPOINT}...")  
   
 try:  
 client = Minio(  
 MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=False  
 )  
   
 if not client.bucket\_exists(BUCKET\_NAME):  
 logger.error(f"❌ Bucket '{BUCKET\_NAME}' does not exist!")  
 return  
  
 logger.info(f"Checking bucket '{BUCKET\_NAME}'...")  
 objects = list(client.list\_objects(BUCKET\_NAME, recursive=True))  
   
 count = len(objects)  
 logger.info(f"✅ Found {count} objects in bucket.")  
   
 if count == 0:  
 logger.warning(" Bucket is empty. Consumer might not have written data yet.")  
 return  
  
 # Check for files matching today's date (formatted as YYYYMMDD in our parquet script)  
 today\_str = datetime.now().strftime("%Y%m%d")  
 today\_files = [o for o in objects if today\_str in o.object\_name]  
   
 if today\_files:  
 logger.info(f"✅ Found {len(today\_files)} files matching today's date pattern ({today\_str}).")  
 logger.info("Sample files:")  
 for o in today\_files[:3]:  
 logger.info(f" - {o.object\_name} ({o.size} bytes)")  
 else:  
 logger.warning(f"⚠️ No files found matching today's date pattern ({today\_str}).")  
 logger.info("Sample of existing files:")  
 for o in objects[:3]:  
 logger.info(f" - {o.object\_name}")  
  
 except Exception as e:  
 logger.error(f"❌ Error verifying MinIO: {e}")  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## src/\_\_init\_\_.py

"""Top-level package for SIEIS."""

## src/app/\_\_init\_\_.py

"""Application package for SIEIS."""

## src/app/api/\_\_init\_\_.py

## src/app/api/main.py

"""SIEIS FastAPI application - main entry point."""  
  
import logging  
import os  
from contextlib import asynccontextmanager  
  
from fastapi import FastAPI  
from fastapi.middleware.cors import CORSMiddleware  
from fastapi.responses import JSONResponse  
  
from src.app.api.routes import sensors, analytics, ml  
from src.app import config  
  
logging.basicConfig(  
 level=getattr(logging, config.LOG\_LEVEL, logging.INFO),  
 format="%(asctime)s [%(levelname)s] %(name)s: %(message)s",  
)  
logger = logging.getLogger(\_\_name\_\_)  
  
  
@asynccontextmanager  
async def lifespan(app: FastAPI):  
 """Startup and shutdown events."""  
 logger.info(f"🚀 SIEIS API starting — env={config.ENVIRONMENT}, influxdb={config.INFLUX\_URL}")  
 yield  
 logger.info("SIEIS API shutting down")  
  
  
app = FastAPI(  
 title=config.API\_TITLE,  
 version=config.API\_VERSION,  
 description="SIEIS — Smart IoT Environmental Information System API",  
 lifespan=lifespan,  
)  
  
# CORS — allow all origins for local development  
app.add\_middleware(  
 CORSMiddleware,  
 allow\_origins=["\*"],  
 allow\_credentials=True,  
 allow\_methods=["\*"],  
 allow\_headers=["\*"],  
)  
  
# Register routers  
app.include\_router(sensors.router, prefix="/api/v1")  
app.include\_router(analytics.router, prefix="/api/v1")  
app.include\_router(ml.router, prefix="/api/v1")  
  
  
@app.get("/", tags=["root"])  
def root():  
 return {"message": "SIEIS API", "version": config.API\_VERSION, "docs": "/docs"}  
  
  
@app.get("/health", tags=["health"])  
@app.get("/api/v1/health", tags=["health"])  
def health():  
 """Basic health check — verifies InfluxDB connectivity."""  
 influx\_status = "unknown"  
 try:  
 from influxdb\_client import InfluxDBClient  
 client = InfluxDBClient(  
 url=config.INFLUX\_URL,  
 token=config.INFLUX\_TOKEN,  
 org=config.INFLUX\_ORG,  
 )  
 ping\_ok = client.ping()  
 influx\_status = "ok" if ping\_ok else "error"  
 client.close()  
 except Exception as e:  
 influx\_status = f"error: {e}"  
  
 # Check if model is loaded  
 from src.app.api.routes.ml import \_get\_model  
 model\_loaded = \_get\_model() is not None  
  
 status = "ok" if influx\_status == "ok" else "degraded"  
 return JSONResponse(  
 status\_code=200,  
 content={  
 "status": status,  
 "influxdb": influx\_status,  
 "model\_loaded": model\_loaded,  
 "version": config.API\_VERSION,  
 },  
 )

## src/app/api/routes/\_\_init\_\_.py

## src/app/api/routes/analytics.py

"""Analytics endpoints - aggregations, trends, statistics."""  
  
import logging  
from typing import List, Optional  
  
from fastapi import APIRouter, HTTPException, Query  
  
from src.app.api.schemas import AggregatedStats  
from src.app import config  
  
logger = logging.getLogger(\_\_name\_\_)  
router = APIRouter(prefix="/analytics", tags=["analytics"])  
  
  
def \_get\_influx\_client():  
 from influxdb\_client import InfluxDBClient  
 return InfluxDBClient(  
 url=config.INFLUX\_URL,  
 token=config.INFLUX\_TOKEN,  
 org=config.INFLUX\_ORG,  
 )  
  
  
@router.get("/summary", summary="Get aggregated stats for a metric")  
def get\_summary(  
 metric: str = Query(..., description="Sensor metric: temperature, humidity, light, voltage"),  
 mote\_id: Optional[str] = Query(default=None, description="Filter by mote ID (optional)"),  
 start: str = Query(default="-24h", description="Start time"),  
):  
 """Return mean, min, max for a given sensor metric over a time window."""  
 valid\_metrics = {"temperature", "humidity", "light", "voltage"}  
 if metric not in valid\_metrics:  
 raise HTTPException(status\_code=400, detail=f"metric must be one of {valid\_metrics}")  
  
 try:  
 client = \_get\_influx\_client()  
 query\_api = client.query\_api()  
 mote\_filter = f'|> filter(fn: (r) => r["mote\_id"] == "{mote\_id}")' if mote\_id else ""  
  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {start})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["\_field"] == "{metric}")  
 {mote\_filter}  
"""  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
  
 values = []  
 for table in tables:  
 for record in table.records:  
 v = record.get\_value()  
 if v is not None:  
 values.append(float(v))  
  
 client.close()  
  
 if not values:  
 return AggregatedStats(  
 mote\_id=mote\_id, metric=metric,  
 mean=None, min=None, max=None, count=0, period=start  
 )  
  
 return AggregatedStats(  
 mote\_id=mote\_id,  
 metric=metric,  
 mean=round(sum(values) / len(values), 4),  
 min=round(min(values), 4),  
 max=round(max(values), 4),  
 count=len(values),  
 period=start,  
 )  
 except Exception as e:  
 logger.exception("Failed to compute summary")  
 raise HTTPException(status\_code=500, detail=str(e))  
  
  
@router.get("/active-motes-count", summary="Count active motes in last 15 minutes")  
def active\_motes\_count():  
 """Return count of motes that reported data in the last 15 minutes."""  
 try:  
 client = \_get\_influx\_client()  
 query\_api = client.query\_api()  
  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: -15m)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> keep(columns: ["mote\_id"])  
 |> distinct(column: "mote\_id")  
 |> count()  
"""  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
 client.close()  
  
 count = 0  
 for table in tables:  
 for record in table.records:  
 count = record.get\_value() or 0  
 return {"active\_motes\_last\_15m": int(count)}  
 except Exception as e:  
 logger.exception("Failed to count active motes")  
 raise HTTPException(status\_code=500, detail=str(e))  
  
  
@router.get("/ingestion-rate", summary="Messages ingested per minute (last 5m)")  
def ingestion\_rate():  
 """Return approximate records-per-minute ingestion rate."""  
 try:  
 client = \_get\_influx\_client()  
 query\_api = client.query\_api()  
  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: -5m)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["\_field"] == "temperature")  
 |> count()  
"""  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
 client.close()  
  
 total = 0  
 for table in tables:  
 for record in table.records:  
 total += record.get\_value() or 0  
 rate = round(total / 5.0, 2)  
 return {"records\_per\_minute": rate, "total\_last\_5m": total}  
 except Exception as e:  
 logger.exception("Failed to compute ingestion rate")  
 raise HTTPException(status\_code=500, detail=str(e))

## src/app/api/routes/ml.py

"""ML inference endpoints - anomaly detection."""  
  
import logging  
import os  
from typing import List  
  
from fastapi import APIRouter, HTTPException  
  
from src.app.api.schemas import AnomalyInput, AnomalyResult  
from src.app import config  
  
logger = logging.getLogger(\_\_name\_\_)  
router = APIRouter(prefix="/ml", tags=["ml"])  
  
# Global model cache (loaded once on first use)  
\_model = None  
\_model\_path = None  
  
  
def \_load\_model():  
 """Load the latest anomaly detection model from models directory."""  
 global \_model, \_model\_path  
 import pickle  
 import json  
  
 registry\_path = config.MODELS\_DIR / "model\_registry.json"  
 if not registry\_path.exists():  
 return None, None  
  
 with open(registry\_path) as f:  
 registry = json.load(f)  
  
 latest = registry.get("latest")  
 if not latest:  
 return None, None  
  
 model\_file = config.MODELS\_DIR / latest  
 if not model\_file.exists():  
 return None, None  
  
 with open(model\_file, "rb") as f:  
 artifact = pickle.load(f)  
  
 # Artifact is a dict {"pipeline": ..., "metrics": ..., "version": ...}  
 if isinstance(artifact, dict) and "pipeline" in artifact:  
 model = artifact["pipeline"]  
 else:  
 model = artifact # backwards compat for plain pipeline pickles  
  
 return model, str(model\_file)  
  
  
def \_get\_model():  
 global \_model, \_model\_path  
 if \_model is None:  
 \_model, \_model\_path = \_load\_model()  
 return \_model  
  
  
def \_score\_to\_severity(score: float) -> str:  
 """Map anomaly score to human-readable severity.  
  
 The anomaly\_score is computed as: 0.5 - decision\_function\_score / 2  
 So the natural split points are:  
 < 0.50 → IsolationForest decision\_function > 0 → model says normal  
 0.50–0.65 → mild anomaly  
 >= 0.65 → clear anomaly  
 """  
 if score >= 0.65:  
 return "critical"  
 elif score >= 0.5:  
 return "warning"  
 return "normal"  
  
  
@router.post("/predict/anomaly", response\_model=AnomalyResult, summary="Predict if a reading is anomalous")  
def predict\_anomaly(body: AnomalyInput):  
 """Run anomaly detection on a single sensor reading.  
   
 Returns an anomaly score (0=normal, 1=anomaly) and severity label.  
 Falls back to a rule-based heuristic if no model is loaded.  
 """  
 model = \_get\_model()  
  
 if model is not None:  
 import numpy as np  
 import pandas as pd  
 from datetime import datetime  
  
 # Build feature vector matching training: temperature, humidity, light, voltage, hour, day\_of\_week  
 now = datetime.utcnow()  
 X = pd.DataFrame([{  
 "temperature": body.temperature,  
 "humidity": body.humidity,  
 "light": body.light,  
 "voltage": body.voltage,  
 "hour": now.hour,  
 "day\_of\_week": now.weekday(),  
 }])  
 # Isolation Forest: predict returns -1 (anomaly) or 1 (normal)  
 raw\_pred = model.predict(X)[0]  
 score\_arr = model.decision\_function(X)[0]  
 # Convert decision function score to 0-1 range (higher = more anomalous)  
 anomaly\_score = float(max(0.0, min(1.0, 0.5 - score\_arr / 2.0)))  
 is\_anomaly = raw\_pred == -1  
 else:  
 # Rule-based fallback when no model is trained yet  
 anomaly\_score = 0.0  
 flags = []  
 if not (15 <= body.temperature <= 45):  
 flags.append("temperature"); anomaly\_score += 0.4  
 if not (20 <= body.humidity <= 90):  
 flags.append("humidity"); anomaly\_score += 0.3  
 if body.light < 0 or body.light > 2000:  
 flags.append("light"); anomaly\_score += 0.2  
 if not (2.0 <= body.voltage <= 3.5):  
 flags.append("voltage"); anomaly\_score += 0.3  
 anomaly\_score = min(1.0, anomaly\_score)  
 is\_anomaly = anomaly\_score > 0.3  
  
 return AnomalyResult(  
 mote\_id=body.mote\_id,  
 anomaly\_score=round(anomaly\_score, 4),  
 is\_anomaly=is\_anomaly,  
 severity=\_score\_to\_severity(anomaly\_score),  
 input=body,  
 )  
  
  
@router.get("/model/info", summary="Get info about the currently loaded model")  
def model\_info():  
 """Return metadata about the loaded anomaly detection model."""  
 import json  
 registry\_path = config.MODELS\_DIR / "model\_registry.json"  
 if registry\_path.exists():  
 with open(registry\_path) as f:  
 registry = json.load(f)  
 else:  
 registry = {}  
  
 model = \_get\_model()  
 return {  
 "model\_loaded": model is not None,  
 "model\_path": \_model\_path,  
 "registry": registry,  
 "fallback\_mode": model is None,  
 }  
  
  
@router.post("/model/reload", summary="Reload model from disk")  
def reload\_model():  
 """Force-reload the latest model from the models directory."""  
 global \_model, \_model\_path  
 \_model, \_model\_path = \_load\_model()  
 return {  
 "reloaded": True,  
 "model\_loaded": \_model is not None,  
 "model\_path": \_model\_path,  
 }

## src/app/api/routes/sensors.py

"""Sensor data query endpoints - reads from InfluxDB."""  
  
import logging  
from typing import List, Optional  
  
from fastapi import APIRouter, HTTPException, Query  
  
from src.app.api.schemas import LatestReading, SensorReading  
from src.app import config  
  
logger = logging.getLogger(\_\_name\_\_)  
router = APIRouter(prefix="/sensors", tags=["sensors"])  
  
  
def \_get\_influx\_client():  
 from influxdb\_client import InfluxDBClient  
 return InfluxDBClient(  
 url=config.INFLUX\_URL,  
 token=config.INFLUX\_TOKEN,  
 org=config.INFLUX\_ORG,  
 )  
  
  
@router.get("/latest", response\_model=List[LatestReading], summary="Get latest reading per mote")  
def get\_latest\_readings(  
 mote\_id: Optional[str] = Query(default=None, description="Filter by mote ID"),  
 window: str = Query(default="-1h", description="Time window, e.g. -1h, -15m, -24h"),  
):  
 """Return the most recent sensor reading for each mote (or a specific mote)."""  
 try:  
 client = \_get\_influx\_client()  
 query\_api = client.query\_api()  
  
 mote\_filter = f'|> filter(fn: (r) => r["mote\_id"] == "{mote\_id}")' if mote\_id else ""  
  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {window})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 {mote\_filter}  
 |> last()  
 |> pivot(rowKey:["\_time","mote\_id"], columnKey: ["\_field"], valueColumn: "\_value")  
"""  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
 client.close()  
  
 results = []  
 for table in tables:  
 for record in table.records:  
 results.append(LatestReading(  
 mote\_id=record.values.get("mote\_id", "unknown"),  
 temperature=record.values.get("temperature"),  
 humidity=record.values.get("humidity"),  
 light=record.values.get("light"),  
 voltage=record.values.get("voltage"),  
 timestamp=str(record.get\_time()) if record.get\_time() else None,  
 ))  
 return results  
 except Exception as e:  
 logger.exception("Failed to query latest readings")  
 raise HTTPException(status\_code=500, detail=str(e))  
  
  
@router.get("/history", response\_model=List[SensorReading], summary="Get sensor readings over time")  
def get\_sensor\_history(  
 mote\_id: str = Query(..., description="Mote ID to query"),  
 start: str = Query(default="-1h", description="Start time, e.g. -1h, -24h, or ISO timestamp"),  
 stop: str = Query(default="now()", description="Stop time"),  
 limit: int = Query(default=500, ge=1, le=5000),  
):  
 """Return time-series sensor readings for a specific mote."""  
 try:  
 client = \_get\_influx\_client()  
 query\_api = client.query\_api()  
  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {start}, stop: {stop})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["mote\_id"] == "{mote\_id}")  
 |> pivot(rowKey:["\_time","mote\_id"], columnKey: ["\_field"], valueColumn: "\_value")  
 |> limit(n: {limit})  
"""  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
 client.close()  
  
 results = []  
 for table in tables:  
 for record in table.records:  
 results.append(SensorReading(  
 mote\_id=record.values.get("mote\_id", mote\_id),  
 temperature=record.values.get("temperature"),  
 humidity=record.values.get("humidity"),  
 light=record.values.get("light"),  
 voltage=record.values.get("voltage"),  
 timestamp=record.get\_time(),  
 ))  
 return results  
 except Exception as e:  
 logger.exception("Failed to query sensor history")  
 raise HTTPException(status\_code=500, detail=str(e))  
  
  
@router.get("/motes", response\_model=List[str], summary="List all active mote IDs")  
def list\_motes(  
 window: str = Query(default="-24h", description="Time window to look for active motes"),  
):  
 """Return list of mote IDs that have data in the given time window."""  
 try:  
 client = \_get\_influx\_client()  
 query\_api = client.query\_api()  
  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {window})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> keep(columns: ["mote\_id"])  
 |> distinct(column: "mote\_id")  
"""  
 tables = query\_api.query(flux, org=config.INFLUX\_ORG)  
 client.close()  
  
 mote\_ids = []  
 for table in tables:  
 for record in table.records:  
 val = record.values.get("mote\_id") or record.get\_value()  
 if val and val not in mote\_ids:  
 mote\_ids.append(str(val))  
 return sorted(mote\_ids)  
 except Exception as e:  
 logger.exception("Failed to list motes")  
 raise HTTPException(status\_code=500, detail=str(e))

## src/app/api/schemas.py

"""Pydantic schemas for SIEIS API request/response models."""  
  
from datetime import datetime  
from typing import List, Optional  
from pydantic import BaseModel, Field  
  
  
class SensorReading(BaseModel):  
 mote\_id: str  
 temperature: Optional[float] = None  
 humidity: Optional[float] = None  
 light: Optional[float] = None  
 voltage: Optional[float] = None  
 timestamp: Optional[datetime] = None  
  
  
class SensorQuery(BaseModel):  
 mote\_id: Optional[str] = None  
 start: str = Field(default="-1h", description="Flux duration or ISO timestamp, e.g. '-1h', '-24h', '2026-01-01T00:00:00Z'")  
 stop: str = Field(default="now()", description="Flux stop time")  
 limit: int = Field(default=500, ge=1, le=10000)  
  
  
class LatestReading(BaseModel):  
 mote\_id: str  
 temperature: Optional[float] = None  
 humidity: Optional[float] = None  
 light: Optional[float] = None  
 voltage: Optional[float] = None  
 timestamp: Optional[str] = None  
  
  
class AggregatedStats(BaseModel):  
 mote\_id: Optional[str] = None  
 metric: str  
 mean: Optional[float] = None  
 min: Optional[float] = None  
 max: Optional[float] = None  
 count: Optional[int] = None  
 period: str  
  
  
class AnomalyInput(BaseModel):  
 temperature: float  
 humidity: float  
 light: float  
 voltage: float  
 mote\_id: Optional[str] = None  
  
  
class AnomalyResult(BaseModel):  
 mote\_id: Optional[str] = None  
 anomaly\_score: float  
 is\_anomaly: bool  
 severity: str # "normal", "warning", "critical"  
 input: AnomalyInput  
  
  
class HealthResponse(BaseModel):  
 status: str  
 influxdb: str  
 model\_loaded: bool  
 version: str = "1.0.0"

## src/app/api\_server.py

"""Entry point to run the SIEIS API server.  
  
Usage:  
 python -m src.app.api\_server  
   
Or with uvicorn directly:  
 uvicorn src.app.api.main:app --host 0.0.0.0 --port 8000 --reload  
"""  
  
import uvicorn  
from dotenv import load\_dotenv  
  
# Load .env before importing config  
load\_dotenv()  
  
from src.app import config  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 uvicorn.run(  
 "src.app.api.main:app",  
 host=config.API\_HOST,  
 port=config.API\_PORT,  
 reload=config.DEBUG,  
 log\_level=config.LOG\_LEVEL.lower(),  
 )

## src/app/config.py

import os  
from pathlib import Path  
  
# ============================================================================  
# PROJECT PATHS  
# ============================================================================  
PROJECT\_ROOT = Path(\_\_file\_\_).parent.parent.parent  
DATA\_DIR = PROJECT\_ROOT / "data"  
LOGS\_DIR = PROJECT\_ROOT / "logs"  
MODELS\_DIR = PROJECT\_ROOT / "src/app/ml/models"  
  
# ============================================================================  
# INFLUXDB CONFIGURATION  
# ============================================================================  
INFLUX\_URL = os.getenv("INFLUX\_URL", "http://localhost:8086")  
INFLUX\_TOKEN = os.getenv("INFLUX\_TOKEN", "my-super-secret-token")  
INFLUX\_ORG = os.getenv("INFLUX\_ORG", "sieis")  
INFLUX\_BUCKET = os.getenv("INFLUX\_BUCKET", "sensor\_data")  
  
# ============================================================================  
# MINIO CONFIGURATION (S3-COMPATIBLE OBJECT STORAGE)  
# ============================================================================  
MINIO\_ENDPOINT = os.getenv("MINIO\_ENDPOINT", "localhost:9000")  
MINIO\_ACCESS\_KEY = os.getenv("MINIO\_ACCESS\_KEY", "minioadmin")  
MINIO\_SECRET\_KEY = os.getenv("MINIO\_SECRET\_KEY", "minioadmin123")  
MINIO\_SECURE = os.getenv("MINIO\_SECURE", "false").lower() == "true"  
MINIO\_BUCKET = os.getenv("MINIO\_BUCKET", "sieis-archive")  
  
# ============================================================================  
# REDPANDA/KAFKA CONFIGURATION  
# ============================================================================  
KAFKA\_BROKER = os.getenv("KAFKA\_BROKER", "localhost:19092") # 29092 was wrong; Redpanda external port is 19092  
KAFKA\_TOPIC = os.getenv("KAFKA\_TOPIC", "sensor\_readings")  
KAFKA\_GROUP = os.getenv("KAFKA\_GROUP", "sieis-consumer-group")  
  
# ============================================================================  
# SIMULATOR CONFIGURATION  
# ============================================================================  
SPEED\_FACTOR = float(os.getenv("SPEED\_FACTOR", "100.0"))  
DATA\_PATH = os.getenv("DATA\_PATH", str(DATA\_DIR / "processed/incremental\_data.txt"))  
MOTE\_LOCS\_PATH = os.getenv("MOTE\_LOCS\_PATH", str(DATA\_DIR / "raw/mote\_locs.txt"))  
FILTER\_TODAY\_ONLY = os.getenv("FILTER\_TODAY\_ONLY", "true").lower() == "true"  
# YEAR\_OFFSET: shifts legacy 2004 timestamps to current year (fallback when updated\_timestamp absent)  
import datetime as \_dt  
YEAR\_OFFSET = int(os.getenv("YEAR\_OFFSET", str(\_dt.datetime.now().year - 2004)))  
  
# ============================================================================  
# API CONFIGURATION  
# ============================================================================  
API\_HOST = os.getenv("API\_HOST", "0.0.0.0")  
API\_PORT = int(os.getenv("API\_PORT", "8000"))  
API\_TITLE = "SIEIS API"  
API\_VERSION = "1.0.0"  
  
# ============================================================================  
# LOGGING CONFIGURATION  
# ============================================================================  
LOG\_LEVEL = os.getenv("LOG\_LEVEL", "INFO")  
LOG\_FILE = LOGS\_DIR / "sieis.log"  
  
# ============================================================================  
# APPLICATION CONFIGURATION  
# ============================================================================  
DEBUG = os.getenv("DEBUG", "false").lower() == "true"  
ENVIRONMENT = os.getenv("ENVIRONMENT", "development")  
  
# ============================================================================  
# VALIDATION  
# ============================================================================  
def validate\_config():  
 """Validate all required configuration is set."""  
 required = [  
 ("INFLUX\_URL", INFLUX\_URL),  
 ("MINIO\_ENDPOINT", MINIO\_ENDPOINT),  
 ("MINIO\_ACCESS\_KEY", MINIO\_ACCESS\_KEY),  
 ("MINIO\_SECRET\_KEY", MINIO\_SECRET\_KEY),  
 ]  
   
 missing = [name for name, value in required if not value]  
   
 if missing:  
 raise ValueError(f"Missing required configuration: {', '.join(missing)}")  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 validate\_config()  
 print("✅ Config validation passed!")

## src/app/consumer/\_\_init\_\_.py

"""Consumer package for SIEIS."""

## src/app/consumer/influx\_writer.py

"""InfluxDB 2.x writer for sensor readings."""  
  
import logging  
from datetime import datetime  
from typing import Dict, Iterable, List, Optional  
  
from influxdb\_client import InfluxDBClient, Point, WritePrecision  
from influxdb\_client.client.write\_api import SYNCHRONOUS  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
class InfluxWriter:  
 """Write batches of sensor readings to InfluxDB 2.x."""  
  
 def \_\_init\_\_(  
 self,  
 url: str,  
 token: str,  
 org: str,  
 bucket: str,  
 measurement: str = "sensor\_reading",  
 ) -> None:  
 """Initialize InfluxDB 2.x writer.  
   
 Args:  
 url: InfluxDB URL (e.g., 'http://localhost:8086')  
 token: Authentication token  
 org: Organization name  
 bucket: Bucket name  
 measurement: Measurement name for time series data  
 """  
 self.org = org  
 self.bucket = bucket  
 self.measurement = measurement  
 self.client = InfluxDBClient(url=url, token=token, org=org)  
 self.write\_api = self.client.write\_api(write\_options=SYNCHRONOUS)  
 logger.info(f"InfluxDB 2.x writer initialized: url={url}, org={org}, bucket={bucket}")  
  
 def \_to\_point(self, message: Dict) -> Optional[Point]:  
 """Convert message dict to InfluxDB Point.  
   
 Uses 'updated\_timestamp' for time field (maps 2004 data to 2025+).  
 """  
 mote\_id = message.get("mote\_id")  
 if mote\_id is None:  
 logger.warning("Message missing mote\_id, skipping")  
 return None  
  
 point = Point(self.measurement).tag("mote\_id", str(mote\_id))  
  
 # Add sensor fields  
 field\_count = 0  
 for field in ("temperature", "humidity", "light", "voltage"):  
 value = message.get(field)  
 if value is not None:  
 point = point.field(field, float(value))  
 field\_count += 1  
  
 if field\_count == 0:  
 logger.warning(f"Message for mote {mote\_id} has no valid fields")  
 return None  
  
 # Use updated\_timestamp (2025+ mapped data) for InfluxDB  
 ts = message.get("updated\_timestamp")  
 if ts is None:  
 # Fallback to regular timestamp if updated\_timestamp not available  
 ts = message.get("timestamp")  
   
 if ts is not None:  
 try:  
 # Parse ISO format timestamp string to datetime  
 if isinstance(ts, str):  
 ts = datetime.fromisoformat(ts.replace('Z', '+00:00'))  
 point = point.time(ts, WritePrecision.NS)  
 except Exception as e:  
 logger.error(f"Failed to parse timestamp '{ts}': {e}")  
 return None  
  
 return point  
  
 def write\_batch(self, messages: Iterable[Dict]) -> None:  
 """Write a batch of messages to InfluxDB 3.x.  
   
 Args:  
 messages: Iterable of sensor reading dictionaries  
 """  
 points: List[Point] = []  
 skipped = 0  
   
 for message in messages:  
 point = self.\_to\_point(message)  
 if point is not None:  
 points.append(point)  
 else:  
 skipped += 1  
  
 if not points:  
 logger.warning(f"No valid points to write (skipped {skipped} invalid messages)")  
 return  
  
 try:  
 logger.info(f"Writing {len(points)} points to InfluxDB bucket={self.bucket}, org={self.org}, measurement={self.measurement}")  
 if skipped > 0:  
 logger.warning(f"Skipped {skipped} invalid messages")  
   
 # InfluxDB 2.x write API  
 self.write\_api.write(bucket=self.bucket, org=self.org, record=points)  
 logger.info(f"Successfully wrote {len(points)} points to measurement '{self.measurement}'")  
 except Exception as e:  
 logger.exception(f"Failed to write batch to InfluxDB: {e}")  
 # Print first point for debugging  
 if points:  
 logger.error(f"Sample point that failed: {points[0].to\_line\_protocol()}")  
 raise # Re-raise to indicate failure  
  
 def close(self) -> None:  
 """Close InfluxDB client connection."""  
 try:  
 self.client.close()  
 logger.info("InfluxDB client closed")  
 except Exception:  
 logger.exception("Failed to close InfluxDB client")

## src/app/consumer/kafka\_consumer.py

"""Kafka consumer that batches messages for downstream processing."""  
  
import json  
import logging  
import time  
from typing import Dict, Iterable, List, Optional  
  
from kafka import KafkaConsumer  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
class KafkaBatchConsumer:  
 """Consume Kafka messages and yield them in batches."""  
  
 def \_\_init\_\_(  
 self,  
 broker: str,  
 topic: str,  
 group\_id: str = "sieis-consumers",  
 batch\_size: int = 100,  
 batch\_timeout: float = 1.0,  
 auto\_offset\_reset: str = "earliest", # "latest" caused messages to be missed if consumer starts after simulator  
 ) -> None:  
 self.topic = topic  
 self.batch\_size = batch\_size  
 self.batch\_timeout = batch\_timeout  
 self.consumer = KafkaConsumer(  
 topic,  
 bootstrap\_servers=[broker],  
 group\_id=group\_id,  
 auto\_offset\_reset=auto\_offset\_reset,  
 enable\_auto\_commit=False,  
 value\_deserializer=lambda m: json.loads(m.decode("utf-8")),  
 )  
  
 def consume\_batches(self) -> Iterable[List[Dict]]:  
 """Yield message batches based on size or time window."""  
 batch: List[Dict] = []  
 batch\_start = time.time()  
  
 while True:  
 records = self.consumer.poll(timeout\_ms=100)  
 for \_, msgs in records.items():  
 for msg in msgs:  
 if msg.value is None:  
 continue  
 batch.append(msg.value)  
  
 now = time.time()  
 if batch and (len(batch) >= self.batch\_size or (now - batch\_start) >= self.batch\_timeout):  
 yield batch  
 batch = []  
 batch\_start = now  
  
 def commit(self) -> None:  
 """Commit current offsets after successful processing."""  
 try:  
 self.consumer.commit()  
 except Exception:  
 logger.exception("Failed to commit Kafka offsets")  
  
 def close(self) -> None:  
 try:  
 self.consumer.close()  
 except Exception:  
 logger.exception("Failed to close Kafka consumer")

## src/app/consumer/main.py

"""Kafka-to-InfluxDB-and-MinIO consumer entry point with dual-write pattern."""  
  
import logging  
from minio import Minio  
  
from src.app.config import (  
 INFLUX\_BUCKET,  
 INFLUX\_ORG,  
 INFLUX\_TOKEN,  
 INFLUX\_URL,  
 KAFKA\_BROKER,  
 KAFKA\_TOPIC,  
 MINIO\_ACCESS\_KEY,  
 MINIO\_BUCKET,  
 MINIO\_ENDPOINT,  
 MINIO\_SECRET\_KEY,  
 MINIO\_SECURE,  
)  
from src.app.consumer.kafka\_consumer import KafkaBatchConsumer  
from src.app.consumer.influx\_writer import InfluxWriter  
from src.app.consumer.parquet\_writer import ParquetWriter  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def run\_consumer() -> None:  
 """Run dual-write consumer: Kafka → InfluxDB (hot, real-time) + MinIO (cold, Parquet)."""  
 logging.basicConfig(level=logging.INFO)  
   
 # Initialize Kafka consumer  
 consumer = KafkaBatchConsumer(broker=KAFKA\_BROKER, topic=KAFKA\_TOPIC)  
   
 # Initialize InfluxDB 2.x writer (hot path - real-time queries)  
 influx\_writer = InfluxWriter(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG,  
 bucket=INFLUX\_BUCKET,  
 )  
   
 # Initialize MinIO client  
 minio\_client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 # Initialize Parquet writer (cold path - historical archive)  
 parquet\_writer = ParquetWriter(  
 minio\_client=minio\_client,  
 bucket\_name=MINIO\_BUCKET  
 )  
   
 logger.info("Consumer started with dual-write pattern: InfluxDB + MinIO")  
 logger.info(f" InfluxDB: {INFLUX\_URL} (org={INFLUX\_ORG}, bucket={INFLUX\_BUCKET})")  
 logger.info(f" MinIO: {MINIO\_ENDPOINT} (bucket={MINIO\_BUCKET})")  
  
 try:  
 for batch in consumer.consume\_batches():  
 # Dual-write pattern: write to both destinations  
 influx\_success = False  
 parquet\_success = False  
   
 # Write to InfluxDB (hot path - critical for real-time dashboard)  
 try:  
 influx\_writer.write\_batch(batch)  
 influx\_success = True  
 except Exception as e:  
 logger.error(f"InfluxDB write failed: {e}")  
 # Continue to try MinIO write even if InfluxDB fails  
   
 # Write to MinIO (cold path - best effort, don't block on failure)  
 try:  
 parquet\_writer.write\_batch(batch)  
 parquet\_success = True  
 except Exception as e:  
 logger.warning(f"MinIO write failed (non-critical): {e}")  
 # Don't block consumer on MinIO failures  
   
 # Commit offset only if InfluxDB write succeeded (critical path)  
 if influx\_success:  
 consumer.commit()  
 if parquet\_success:  
 logger.debug("Dual-write successful: InfluxDB + MinIO")  
 else:  
 logger.warning("Partial write: InfluxDB succeeded, MinIO failed")  
 else:  
 logger.error("Skipping Kafka commit due to InfluxDB write failure")  
   
 except KeyboardInterrupt:  
 logger.info("KeyboardInterrupt received - stopping consumer")  
 finally:  
 consumer.close()  
 influx\_writer.close()  
 parquet\_writer.close()  
 logger.info("Consumer shutdown complete")  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 run\_consumer()

## src/app/consumer/parquet\_writer.py

"""MinIO Parquet writer for historical sensor data archive."""  
  
import logging  
import hashlib  
from io import BytesIO  
from typing import Dict, List, Set, Tuple  
from datetime import datetime, timezone  
  
import pandas as pd  
import pyarrow as pa  
import pyarrow.parquet as pq  
from minio import Minio  
from minio.error import S3Error  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
class ParquetWriter:  
 """Write sensor data batches to MinIO as Parquet files with date partitioning."""  
  
 def \_\_init\_\_(self, minio\_client: Minio, bucket\_name: str, enable\_deduplication: bool = True) -> None:  
 """Initialize ParquetWriter with MinIO client.  
   
 Args:  
 minio\_client: Initialized MinIO client  
 bucket\_name: Target bucket name (e.g., 'sieis-archive')  
 enable\_deduplication: Enable in-memory deduplication of messages (default: True)  
 """  
 self.minio\_client = minio\_client  
 self.bucket\_name = bucket\_name  
 self.enable\_deduplication = enable\_deduplication  
   
 # In-memory cache of seen (mote\_id, timestamp) pairs for deduplication  
 self.\_seen\_keys: Set[Tuple[int, str]] = set()  
   
 # Ensure bucket exists  
 if not self.minio\_client.bucket\_exists(bucket\_name):  
 logger.warning(f"Bucket '{bucket\_name}' does not exist, attempting to create")  
 try:  
 self.minio\_client.make\_bucket(bucket\_name)  
 logger.info(f"Created bucket '{bucket\_name}'")  
 except Exception as e:  
 logger.error(f"Failed to create bucket '{bucket\_name}': {e}")  
 raise  
  
 def \_deduplicate\_messages(self, messages: List[Dict]) -> List[Dict]:  
 """Remove duplicate messages based on (mote\_id, timestamp) key.  
   
 Args:  
 messages: List of sensor reading dictionaries  
   
 Returns:  
 Deduplicated list of messages  
 """  
 if not self.enable\_deduplication:  
 return messages  
   
 deduplicated = []  
 initial\_count = len(messages)  
   
 for msg in messages:  
 # Use updated\_timestamp if available, otherwise regular timestamp  
 ts = msg.get("updated\_timestamp") or msg.get("timestamp")  
 if ts is None:  
 logger.warning(f"Message missing timestamp, including anyway: {msg}")  
 deduplicated.append(msg)  
 continue  
   
 key = (msg.get("mote\_id"), str(ts))  
 if key not in self.\_seen\_keys:  
 self.\_seen\_keys.add(key)  
 deduplicated.append(msg)  
   
 if initial\_count > len(deduplicated):  
 logger.info(f"Deduplicated {initial\_count - len(deduplicated)} duplicate messages")  
   
 return deduplicated  
   
 def clear\_deduplication\_cache(self) -> None:  
 """Clear the in-memory deduplication cache.  
   
 Call this periodically to prevent unbounded memory growth in long-running processes.  
 """  
 logger.info(f"Clearing deduplication cache ({len(self.\_seen\_keys)} entries)")  
 self.\_seen\_keys.clear()  
  
 def write\_batch(self, messages: List[Dict]) -> None:  
 """Convert message batch to Parquet and upload to MinIO.  
   
 Messages are partitioned by date extracted from updated\_timestamp.  
 File path structure: year=YYYY/month=MM/day=DD/mote\_id=X/batch\_TIMESTAMP.parquet  
   
 Uses deterministic filenames based on content to ensure idempotency.  
 Deduplicates messages to prevent duplicate data.  
   
 Args:  
 messages: List of sensor reading dictionaries  
 """  
 if not messages:  
 logger.warning("Empty batch provided to ParquetWriter, skipping")  
 return  
  
 try:  
 # Deduplicate messages first  
 messages = self.\_deduplicate\_messages(messages)  
   
 if not messages:  
 logger.info("All messages were duplicates, skipping write")  
 return  
   
 # Convert to DataFrame  
 df = pd.DataFrame(messages)  
   
 # Parse updated\_timestamp for partitioning  
 if "updated\_timestamp" not in df.columns:  
 logger.error("Messages missing 'updated\_timestamp' field, cannot partition")  
 return  
   
 df["updated\_timestamp"] = pd.to\_datetime(df["updated\_timestamp"])  
   
 # Extract partition columns  
 df["year"] = df["updated\_timestamp"].dt.year  
 df["month"] = df["updated\_timestamp"].dt.month.astype(str).str.zfill(2)  
 df["day"] = df["updated\_timestamp"].dt.day.astype(str).str.zfill(2)  
   
 # Group by partition and mote\_id for efficient storage  
 grouped = df.groupby(["year", "month", "day", "mote\_id"])  
   
 upload\_count = 0  
 skipped\_count = 0  
 for (year, month, day, mote\_id), group in grouped:  
 try:  
 # Create deterministic filename based on content (idempotent)  
 min\_ts = group["updated\_timestamp"].min().strftime("%Y%m%d\_%H%M%S")  
 max\_ts = group["updated\_timestamp"].max().strftime("%Y%m%d\_%H%M%S")  
 record\_count = len(group)  
   
 # Create content hash for additional uniqueness (in case same time range)  
 content\_str = f"{min\_ts}\_{max\_ts}\_{record\_count}\_{mote\_id}"  
 content\_hash = hashlib.sha256(content\_str.encode()).hexdigest()[:8]  
   
 object\_name = f"year={year}/month={month}/day={day}/mote\_id={mote\_id}/batch\_{min\_ts}\_{max\_ts}\_{record\_count}\_{content\_hash}.parquet"  
   
 # Check if file already exists (idempotency - skip if exists)  
 try:  
 self.minio\_client.stat\_object(self.bucket\_name, object\_name)  
 logger.debug(f"File {object\_name} already exists, skipping upload (idempotent)")  
 skipped\_count += 1  
 continue  
 except S3Error as e:  
 if e.code != "NoSuchKey":  
 logger.error(f"Error checking object existence for {object\_name}: {e}")  
 # If checking fails, try to proceed with upload anyway or continue?   
 # Safer to log and attempt upload, or just raise.   
 # Let's attempt upload, worst case it overwrites or fails.  
 # File doesn't exist, proceed with upload  
   
 # Drop partition columns (already in path) and write to buffer  
 parquet\_df = group.drop(columns=["year", "month", "day"])  
 buffer = BytesIO()  
   
 # Write Parquet to in-memory buffer  
 table = pa.Table.from\_pandas(parquet\_df)  
 pq.write\_table(table, buffer, compression="snappy")  
   
 # Upload to MinIO  
 buffer.seek(0)  
 self.minio\_client.put\_object(  
 bucket\_name=self.bucket\_name,  
 object\_name=object\_name,  
 data=buffer,  
 length=buffer.getbuffer().nbytes,  
 content\_type="application/octet-stream"  
 )  
   
 upload\_count += 1  
 logger.debug(f"Uploaded {len(group)} records to {object\_name}")  
  
 except Exception as e:  
 logger.error(f"Failed to process group for mote {mote\_id} (year={year}, month={month}, day={day}): {e}")  
 # Continue to next group instead of failing the whole batch  
 continue  
   
 if skipped\_count > 0:  
 logger.info(f"Successfully wrote {len(messages)} messages to MinIO: {upload\_count} new files, {skipped\_count} skipped (already exist)")  
 else:  
 logger.info(f"Successfully wrote {len(messages)} messages to MinIO as {upload\_count} Parquet files")  
   
 except Exception as e:  
 logger.exception(f"Failed to write batch to MinIO: {e}")  
 # Don't raise - we don't want Parquet write failures to block InfluxDB writes  
  
 def close(self) -> None:  
 """Cleanup resources (MinIO client doesn't need explicit closing)."""  
 pass

## src/app/dashboard/\_\_init\_\_.py

# SIEIS Dashboard package

## src/app/dashboard/app.py

"""SIEIS Streamlit Dashboard — main entry point.  
  
Usage:  
 streamlit run src/app/dashboard/app.py  
  
Or via the run script:  
 python scripts/run\_dashboard.py  
"""  
  
import os  
import sys  
  
# Ensure project root is in path  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_))))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import streamlit as st  
  
st.set\_page\_config(  
 page\_title="SIEIS — Smart IoT Sensor Dashboard",  
 page\_icon="📡",  
 layout="wide",  
 initial\_sidebar\_state="expanded",  
)  
  
# ─── Home page content ───────────────────────────────────────────────────────  
st.title("📡 SIEIS — Smart IoT Environmental Information System")  
st.markdown("---")  
  
col1, col2, col3, col4 = st.columns(4)  
  
with col1:  
 st.metric("Data Source", "Intel Lab Dataset", delta="54 motes")  
  
with col2:  
 st.metric("Sensors", "4 metrics", delta="Temp / Humidity / Light / Voltage")  
  
with col3:  
 st.metric("Storage", "Dual-write", delta="InfluxDB + MinIO")  
  
with col4:  
 st.metric("ML Model", "Isolation Forest", delta="Anomaly Detection")  
  
st.markdown("---")  
  
st.markdown("""  
## Welcome to SIEIS Dashboard  
  
Use the \*\*sidebar\*\* to navigate between views:  
  
| Page | Purpose |  
|------|---------|  
| 🔴 Real-time Monitor | Live sensor data from InfluxDB (last 1h–24h) |  
| 📈 Historical Analysis | Long-term trends from MinIO Parquet archives |  
| 🤖 Anomaly Detection | ML-powered anomaly analysis and alerts |  
  
### Quick Start  
1. Make sure Docker containers are running: `docker compose up -d`  
2. Verify data is flowing: `python scripts/verify\_influxDb.py`  
3. Train the ML model: `python scripts/train\_model.py`  
4. Start the API: `python -m src.app.api\_server`  
  
### System Architecture  
```  
Sensors → Simulator → Redpanda/Kafka → Consumer ┬→ InfluxDB (hot) → API → Dashboard  
 └→ MinIO (cold) → ML → Dashboard  
```  
""")  
  
st.sidebar.success("Select a page above ☝️")

## src/app/dashboard/pages/1\_Realtime\_Monitor.py

"""Real-time sensor monitoring page — queries InfluxDB directly."""  
  
import os  
import sys  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.dirname(os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_)))))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import time  
import logging  
from typing import List, Optional  
import pandas as pd  
import plotly.express as px  
import plotly.graph\_objects as go  
import streamlit as st  
  
logger = logging.getLogger(\_\_name\_\_)  
  
st.set\_page\_config(page\_title="Real-time Monitor", page\_icon="🔴", layout="wide")  
st.title("🔴 Real-time Sensor Monitor")  
st.caption("Live data from InfluxDB — auto-refreshes every 30 seconds")  
  
from src.app import config  
  
  
@st.cache\_resource  
def get\_influx\_client():  
 from influxdb\_client import InfluxDBClient  
 return InfluxDBClient(url=config.INFLUX\_URL, token=config.INFLUX\_TOKEN, org=config.INFLUX\_ORG)  
  
  
def query\_influx(flux: str) -> pd.DataFrame:  
 """Run a Flux query and return results as DataFrame."""  
 try:  
 client = get\_influx\_client()  
 query\_api = client.query\_api()  
 tables = query\_api.query\_data\_frame(flux, org=config.INFLUX\_ORG)  
 if isinstance(tables, list):  
 if not tables:  
 return pd.DataFrame()  
 df = pd.concat(tables, ignore\_index=True)  
 else:  
 df = tables  
 # Drop internal InfluxDB columns  
 drop\_cols = [c for c in df.columns if c.startswith("\_") and c not in ["\_value", "\_time", "\_field"]]  
 df = df.drop(columns=drop\_cols, errors="ignore")  
 return df  
 except Exception as e:  
 st.warning(f"InfluxDB query failed: {e}")  
 return pd.DataFrame()  
  
  
# ─── Sidebar Controls ─────────────────────────────────────────────────────────  
with st.sidebar:  
 st.header("⚙️ Controls")  
 time\_window = st.selectbox(  
 "Time window",  
 options=["-15m", "-1h", "-6h", "-24h"],  
 index=1,  
 format\_func=lambda x: {"‑15m": "Last 15 min", "-15m": "Last 15 min", "-1h": "Last 1 hour", "-6h": "Last 6 hours", "-24h": "Last 24 hours"}.get(x, x),  
 )  
 metric = st.selectbox("Metric to plot", ["temperature", "humidity", "light", "voltage"])  
 auto\_refresh = st.checkbox("Auto-refresh (30s)", value=False)  
  
 st.markdown("---")  
 st.markdown("\*\*Connection\*\*")  
 st.code(f"InfluxDB: {config.INFLUX\_URL}\nBucket: {config.INFLUX\_BUCKET}", language="text")  
  
# ─── KPI Row ──────────────────────────────────────────────────────────────────  
st.subheader("📊 Key Metrics")  
  
flux\_active = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: -15m)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> keep(columns: ["mote\_id"])  
 |> distinct(column: "mote\_id")  
 |> count()  
"""  
  
flux\_summary = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {time\_window})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["\_field"] == "{metric}")  
 |> mean()  
"""  
  
col1, col2, col3, col4 = st.columns(4)  
  
df\_active = query\_influx(flux\_active)  
active\_count = 0  
if not df\_active.empty and "\_value" in df\_active.columns:  
 active\_count = int(df\_active["\_value"].iloc[0])  
elif not df\_active.empty:  
 active\_count = len(df\_active)  
  
col1.metric("Active Motes (15m)", active\_count, delta=None)  
  
df\_avg = query\_influx(flux\_summary)  
if not df\_avg.empty and "\_value" in df\_avg.columns:  
 avg\_val = round(df\_avg["\_value"].mean(), 2)  
 col2.metric(f"Avg {metric.title()}", avg\_val)  
else:  
 col2.metric(f"Avg {metric.title()}", "N/A")  
  
# Count total records  
flux\_count = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {time\_window})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["\_field"] == "temperature")  
 |> count()  
"""  
df\_count = query\_influx(flux\_count)  
total\_recs = 0  
if not df\_count.empty and "\_value" in df\_count.columns:  
 total\_recs = int(df\_count["\_value"].sum())  
col3.metric("Total Records", f"{total\_recs:,}")  
col4.metric("Time Window", time\_window)  
  
# ─── Time Series Chart ─────────────────────────────────────────────────────────  
st.subheader(f"📈 {metric.title()} Over Time")  
  
flux\_ts = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {time\_window})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> filter(fn: (r) => r["\_field"] == "{metric}")  
 |> aggregateWindow(every: 1m, fn: mean, createEmpty: false)  
"""  
  
df\_ts = query\_influx(flux\_ts)  
  
if not df\_ts.empty and "\_value" in df\_ts.columns:  
 time\_col = "\_time" if "\_time" in df\_ts.columns else df\_ts.columns[0]  
 mote\_col = "mote\_id" if "mote\_id" in df\_ts.columns else None  
  
 if mote\_col:  
 # Show top 5 motes to avoid clutter  
 top\_motes = df\_ts.groupby(mote\_col)["\_value"].count().nlargest(5).index.tolist()  
 df\_plot = df\_ts[df\_ts[mote\_col].isin(top\_motes)]  
 fig = px.line(  
 df\_plot, x=time\_col, y="\_value", color=mote\_col,  
 title=f"{metric.title()} — Top 5 most active motes",  
 labels={"\_value": metric, time\_col: "Time", mote\_col: "Mote"},  
 )  
 else:  
 fig = px.line(df\_ts, x=time\_col, y="\_value",  
 title=f"{metric.title()} over time",  
 labels={"\_value": metric})  
  
 fig.update\_layout(height=400, legend=dict(orientation="h", yanchor="bottom", y=1.02))  
 st.plotly\_chart(fig, use\_container\_width=True)  
else:  
 st.info("No data available for the selected time window. Make sure the simulator and consumer are running.")  
  
# ─── Latest readings grid ──────────────────────────────────────────────────────  
st.subheader("🗃️ Latest Reading per Mote")  
  
flux\_latest = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: {time\_window})  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> last()  
 |> pivot(rowKey:["\_time","mote\_id"], columnKey: ["\_field"], valueColumn: "\_value")  
"""  
  
df\_latest = query\_influx(flux\_latest)  
if not df\_latest.empty:  
 display\_cols = [c for c in ["mote\_id", "temperature", "humidity", "light", "voltage", "\_time"] if c in df\_latest.columns]  
 df\_display = df\_latest[display\_cols].copy()  
 if "\_time" in df\_display.columns:  
 df\_display = df\_display.rename(columns={"\_time": "last\_seen"})  
 for col in ["temperature", "humidity", "light", "voltage"]:  
 if col in df\_display.columns:  
 df\_display[col] = df\_display[col].round(2)  
 st.dataframe(df\_display.sort\_values("mote\_id") if "mote\_id" in df\_display.columns else df\_display, use\_container\_width=True)  
else:  
 st.info("No recent data. Ensure the data pipeline is running.")  
  
# ─── Auto-refresh ──────────────────────────────────────────────────────────────  
if auto\_refresh:  
 time.sleep(30)  
 st.rerun()

## src/app/dashboard/pages/2\_Historical\_Analysis.py

"""Historical data analysis — queries MinIO Parquet files."""  
  
import os  
import sys  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.dirname(os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_)))))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import io  
import logging  
import pandas as pd  
import plotly.express as px  
import plotly.graph\_objects as go  
import streamlit as st  
  
logger = logging.getLogger(\_\_name\_\_)  
  
st.set\_page\_config(page\_title="Historical Analysis", page\_icon="📈", layout="wide")  
st.title("📈 Historical Sensor Analysis")  
st.caption("Long-term trends from MinIO cold storage (Parquet files)")  
  
from src.app import config  
  
  
@st.cache\_data(ttl=300)  
def load\_local\_data(max\_rows: int = 100\_000) -> pd.DataFrame:  
 """Load from local historical\_data.txt (fallback when MinIO is empty)."""  
 hist\_path = config.DATA\_DIR / "processed" / "historical\_data.txt"  
 if not hist\_path.exists():  
 return pd.DataFrame()  
 cols = ["date", "time", "epoch", "mote\_id", "temperature", "humidity", "light", "voltage", "updated\_timestamp"]  
 df = pd.read\_csv(str(hist\_path), sep=r"\s+", names=cols, na\_values=["N/A", "nan", ""], nrows=max\_rows, on\_bad\_lines="skip")  
 df["timestamp"] = pd.to\_datetime(df["date"] + " " + df["time"], errors="coerce")  
 # Normalize mote\_id to plain int — mixed int/float parsing causes duplicates (e.g. 1 vs 1.0)  
 df["mote\_id"] = pd.to\_numeric(df["mote\_id"], errors="coerce").astype("Int64")  
 for col in ["temperature", "humidity", "light", "voltage"]:  
 df[col] = pd.to\_numeric(df[col], errors="coerce")  
 df = df.dropna(subset=["temperature", "humidity"], how="all")  
 return df  
  
  
@st.cache\_data(ttl=300)  
def load\_minio\_data(max\_rows: int = 500\_000) -> pd.DataFrame:  
 """Load ALL Parquet files from MinIO in parallel, capped at max\_rows total rows."""  
 from concurrent.futures import ThreadPoolExecutor, as\_completed  
 from minio import Minio  
  
 try:  
 client = Minio(  
 config.MINIO\_ENDPOINT,  
 access\_key=config.MINIO\_ACCESS\_KEY,  
 secret\_key=config.MINIO\_SECRET\_KEY,  
 secure=config.MINIO\_SECURE,  
 )  
 objects = list(client.list\_objects(config.MINIO\_BUCKET, recursive=True))  
 parquet\_objects = sorted(  
 [o for o in objects if o.object\_name.endswith(".parquet")],  
 key=lambda o: o.object\_name,  
 )  
 if not parquet\_objects:  
 return pd.DataFrame()  
  
 def \_fetch(obj\_name: str):  
 """Download one Parquet file and return a DataFrame."""  
 try:  
 # Each thread needs its own client instance (not thread-safe to share)  
 \_client = Minio(  
 config.MINIO\_ENDPOINT,  
 access\_key=config.MINIO\_ACCESS\_KEY,  
 secret\_key=config.MINIO\_SECRET\_KEY,  
 secure=config.MINIO\_SECURE,  
 )  
 resp = \_client.get\_object(config.MINIO\_BUCKET, obj\_name)  
 data = resp.read()  
 resp.close()  
 return pd.read\_parquet(io.BytesIO(data))  
 except Exception as e:  
 logger.warning(f"Failed to load {obj\_name}: {e}")  
 return pd.DataFrame()  
  
 frames = []  
 total\_rows = 0  
 # Use up to 8 parallel workers — saturates MinIO I/O without overwhelming it  
 with ThreadPoolExecutor(max\_workers=8) as pool:  
 futures = {  
 pool.submit(\_fetch, obj.object\_name): obj.object\_name  
 for obj in parquet\_objects  
 }  
 for future in as\_completed(futures):  
 if total\_rows >= max\_rows:  
 future.cancel()  
 continue  
 chunk = future.result()  
 if not chunk.empty:  
 frames.append(chunk)  
 total\_rows += len(chunk)  
  
 if not frames:  
 return pd.DataFrame()  
  
 df = pd.concat(frames, ignore\_index=True)  
 # Sort chronologically after parallel assembly  
 if "timestamp" in df.columns:  
 df = df.sort\_values("timestamp").reset\_index(drop=True)  
 # Apply row cap  
 if len(df) > max\_rows:  
 df = df.iloc[:max\_rows]  
 # Normalize mote\_id to plain int  
 if "mote\_id" in df.columns:  
 df["mote\_id"] = pd.to\_numeric(df["mote\_id"], errors="coerce").astype("Int64")  
 return df  
  
 except Exception as e:  
 logger.warning(f"MinIO load failed: {e}")  
 return pd.DataFrame()  
  
  
# ─── Sidebar Controls ─────────────────────────────────────────────────────────  
import datetime as \_dt  
  
# Retrieve saved data bounds from session\_state (populated after first load)  
\_saved\_min: \_dt.date | None = st.session\_state.get("data\_min")  
\_saved\_max: \_dt.date | None = st.session\_state.get("data\_max")  
  
with st.sidebar:  
 st.header("⚙️ Controls")  
 data\_source = st.radio("Data source", ["Local file", "MinIO Parquet"])  
 max\_rows = st.slider("Max rows to load", 10\_000, 2\_000\_000, 500\_000, 10\_000)  
 selected\_metric = st.selectbox("Metric", ["temperature", "humidity", "light", "voltage"])  
  
 st.markdown("---")  
 st.markdown("\*\*🗓️ Date Range Filter\*\*")  
 if \_saved\_min and \_saved\_max:  
 date\_start = st.date\_input(  
 "Start Date", value=\_saved\_min,  
 min\_value=\_saved\_min, max\_value=\_saved\_max,  
 key="date\_start",  
 )  
 date\_end = st.date\_input(  
 "End Date", value=\_saved\_max,  
 min\_value=\_saved\_min, max\_value=\_saved\_max,  
 key="date\_end",  
 )  
 else:  
 st.caption("Loading data to determine date range…")  
 date\_start = date\_end = None  
  
 st.markdown("---")  
 if data\_source == "MinIO Parquet":  
 st.code(f"MinIO: {config.MINIO\_ENDPOINT}\nBucket: {config.MINIO\_BUCKET}", language="text")  
 st.caption("All Parquet files loaded. Use the slider to limit total rows.")  
 else:  
 st.code("File: data/processed/historical\_data.txt", language="text")  
  
# ─── Load data ────────────────────────────────────────────────────────────────  
\_cache\_col, \_btn\_col = st.columns([5, 1])  
with \_btn\_col:  
 if st.button("🔄 Refresh", help="Clear cache and reload data from source"):  
 load\_minio\_data.clear()  
 load\_local\_data.clear()  
 st.session\_state.pop("data\_min", None)  
 st.session\_state.pop("data\_max", None)  
 st.rerun()  
  
if data\_source == "MinIO Parquet":  
 with st.spinner("Loading Parquet files from MinIO in parallel — results are cached for 5 min after first load…"):  
 df = load\_minio\_data(max\_rows)  
 if df.empty:  
 st.warning("No Parquet files found in MinIO. Loading from local file instead.")  
 df = load\_local\_data(max\_rows)  
else:  
 with st.spinner("Loading local data file…"):  
 df = load\_local\_data(max\_rows)  
  
if df.empty:  
 st.error("No data available. Run `python scripts/load\_historical\_data.py` first.")  
 st.stop()  
  
# Ensure timestamp column  
if "timestamp" not in df.columns and "date" in df.columns and "time" in df.columns:  
 df["timestamp"] = pd.to\_datetime(df["date"] + " " + df["time"], errors="coerce")  
elif "timestamp" not in df.columns and "\_time" in df.columns:  
 df["timestamp"] = pd.to\_datetime(df["\_time"], errors="coerce")  
  
# Force timestamp to proper datetime dtype regardless of source  
if "timestamp" in df.columns:  
 df["timestamp"] = pd.to\_datetime(df["timestamp"], errors="coerce")  
  
# Ensure numeric sensor cols  
for col in ["temperature", "humidity", "light", "voltage"]:  
 if col in df.columns:  
 df[col] = pd.to\_numeric(df[col], errors="coerce")  
  
# ─── Save data bounds to session\_state, rerun once so pickers appear ──────────  
if "timestamp" in df.columns:  
 \_ts = df["timestamp"].dropna()  
 if len(\_ts) > 0:  
 \_new\_min, \_new\_max = \_ts.min().date(), \_ts.max().date()  
 if st.session\_state.get("data\_min") != \_new\_min or st.session\_state.get("data\_max") != \_new\_max:  
 st.session\_state["data\_min"] = \_new\_min  
 st.session\_state["data\_max"] = \_new\_max  
 st.rerun() # re-render sidebar with correct picker bounds  
  
# ─── Apply date filter ────────────────────────────────────────────────────────  
if date\_start and date\_end and "timestamp" in df.columns:  
 mask = (df["timestamp"].dt.date >= date\_start) & (df["timestamp"].dt.date <= date\_end)  
 df = df[mask].reset\_index(drop=True)  
 if df.empty:  
 st.warning("No records in the selected date range. Adjust the filter in the sidebar.")  
 st.stop()  
  
# ─── Sidebar stats (injected after filter applied) ────────────────────────────  
with st.sidebar:  
 st.markdown("\*\*📊 Dataset Stats\*\*")  
 st.metric("Records", f"{len(df):,}")  
 st.metric("Unique Motes", df["mote\_id"].nunique() if "mote\_id" in df.columns else "N/A")  
  
# ─── KPI Row ──────────────────────────────────────────────────────────────────  
st.subheader("📊 Dataset Overview")  
col1, col2, col3, col4 = st.columns(4)  
col1.metric("Total Records", f"{len(df):,}")  
col2.metric("Unique Motes", df["mote\_id"].nunique() if "mote\_id" in df.columns else "N/A")  
if "timestamp" in df.columns:  
 ts = df["timestamp"].dropna()  
 if len(ts) > 0:  
 col3.metric("Date Range Start", str(ts.min().date()))  
 col4.metric("Date Range End", str(ts.max().date()))  
  
# ─── Daily averages chart ─────────────────────────────────────────────────────  
st.subheader(f"📅 Daily Average {selected\_metric.title()}")  
  
if "timestamp" in df.columns and selected\_metric in df.columns:  
 df\_daily = df.copy()  
 df\_daily["date"] = df\_daily["timestamp"].dt.date  
 daily\_avg = df\_daily.groupby("date")[selected\_metric].mean().reset\_index()  
 daily\_avg.columns = ["date", "avg\_value"]  
 daily\_avg = daily\_avg.dropna()  
  
 if not daily\_avg.empty:  
 fig\_daily = px.line(  
 daily\_avg, x="date", y="avg\_value",  
 title=f"Daily Average {selected\_metric.title()}",  
 labels={"avg\_value": selected\_metric, "date": "Date"},  
 )  
 fig\_daily.update\_traces(line\_color="#1f77b4")  
 fig\_daily.update\_layout(height=350)  
 st.plotly\_chart(fig\_daily, use\_container\_width=True)  
 else:  
 st.info("No daily data to display.")  
else:  
 st.info("Timestamp or metric column not available in this dataset.")  
  
# ─── Hourly heatmap ───────────────────────────────────────────────────────────  
st.subheader(f"🌡️ Hourly Seasonality Heatmap — {selected\_metric.title()}")  
  
if "timestamp" in df.columns and selected\_metric in df.columns:  
 df\_heat = df.copy()  
 df\_heat["hour"] = df\_heat["timestamp"].dt.hour  
 df\_heat["day\_of\_week"] = df\_heat["timestamp"].dt.day\_name()  
  
 heat\_pivot = (  
 df\_heat.groupby(["day\_of\_week", "hour"])[selected\_metric]  
 .mean()  
 .reset\_index()  
 .pivot(index="day\_of\_week", columns="hour", values=selected\_metric)  
 )  
  
 day\_order = ["Monday", "Tuesday", "Wednesday", "Thursday", "Friday", "Saturday", "Sunday"]  
 heat\_pivot = heat\_pivot.reindex([d for d in day\_order if d in heat\_pivot.index])  
  
 if not heat\_pivot.empty:  
 fig\_heat = px.imshow(  
 heat\_pivot,  
 title=f"{selected\_metric.title()} by Hour & Day of Week",  
 labels={"x": "Hour of Day", "y": "Day", "color": selected\_metric},  
 color\_continuous\_scale="RdYlGn",  
 aspect="auto",  
 )  
 fig\_heat.update\_layout(height=350)  
 st.plotly\_chart(fig\_heat, use\_container\_width=True)  
  
# ─── Distribution ─────────────────────────────────────────────────────────────  
st.subheader(f"📊 Value Distribution — {selected\_metric.title()}")  
  
if selected\_metric in df.columns:  
 col\_a, col\_b = st.columns(2)  
  
 with col\_a:  
 fig\_hist = px.histogram(  
 df.dropna(subset=[selected\_metric]),  
 x=selected\_metric, nbins=50,  
 title=f"Distribution of {selected\_metric}",  
 color\_discrete\_sequence=["#636EFA"],  
 )  
 fig\_hist.update\_layout(height=350)  
 st.plotly\_chart(fig\_hist, use\_container\_width=True)  
  
 with col\_b:  
 if "mote\_id" in df.columns:  
 box\_df = df.dropna(subset=[selected\_metric])  
 top\_motes = box\_df["mote\_id"].value\_counts().nlargest(8).index  
 box\_df = box\_df[box\_df["mote\_id"].isin(top\_motes)]  
 fig\_box = px.box(  
 box\_df, x="mote\_id", y=selected\_metric,  
 title=f"{selected\_metric.title()} by Mote (top 8)",  
 color="mote\_id",  
 )  
 fig\_box.update\_layout(height=350, showlegend=False)  
 st.plotly\_chart(fig\_box, use\_container\_width=True)  
  
# ─── Raw data preview ─────────────────────────────────────────────────────────  
with st.expander("🔍 Raw data sample (first 200 rows)"):  
 preview\_cols = [c for c in ["mote\_id", "timestamp", "temperature", "humidity", "light", "voltage"] if c in df.columns]  
 st.dataframe(df[preview\_cols].head(200), use\_container\_width=True)

## src/app/dashboard/pages/3\_Anomaly\_Detection.py

"""Anomaly detection page — ML model inference via the SIEIS API."""  
  
import os  
import sys  
sys.path.insert(0, os.path.dirname(os.path.dirname(os.path.dirname(os.path.dirname(os.path.dirname(os.path.abspath(\_\_file\_\_)))))))  
  
from dotenv import load\_dotenv  
load\_dotenv()  
  
import json  
import logging  
import pandas as pd  
import plotly.express as px  
import plotly.graph\_objects as go  
import requests  
import streamlit as st  
  
logger = logging.getLogger(\_\_name\_\_)  
  
st.set\_page\_config(page\_title="Anomaly Detection", page\_icon="🤖", layout="wide")  
st.title("🤖 Anomaly Detection")  
st.caption("ML-powered anomaly analysis using Isolation Forest")  
  
from src.app import config  
  
\_api\_url = os.getenv("API\_URL", f"http://localhost:{config.API\_PORT}")  
API\_BASE = f"{\_api\_url}/api/v1"  
  
  
def call\_api(path: str, method: str = "GET", body: dict = None):  
 """Call the SIEIS API with error handling."""  
 try:  
 url = f"{API\_BASE}{path}"  
 if method == "POST":  
 resp = requests.post(url, json=body, timeout=5)  
 else:  
 resp = requests.get(url, timeout=5)  
 resp.raise\_for\_status()  
 return resp.json(), None  
 except requests.exceptions.ConnectionError:  
 return None, "API not running. Start it with: python -m src.app.api\_server"  
 except Exception as e:  
 return None, str(e)  
  
  
# ─── API Status ───────────────────────────────────────────────────────────────  
health\_data, health\_err = call\_api("/health", method="GET")  
  
col\_status, col\_model = st.columns(2)  
with col\_status:  
 if health\_err:  
 st.error(f"❌ API Offline — {health\_err}")  
 api\_online = False  
 else:  
 st.success("✅ API Online")  
 api\_online = True  
  
with col\_model:  
 if api\_online and health\_data:  
 model\_loaded = health\_data.get("model\_loaded", False)  
 if model\_loaded:  
 st.success("✅ ML Model Loaded")  
 else:  
 st.warning("⚠️ Model not trained yet — using rule-based fallback")  
 st.caption("Run: `python scripts/train\_model.py` to train the model")  
  
st.markdown("---")  
  
# ─── Model Info ───────────────────────────────────────────────────────────────  
if api\_online:  
 with st.expander("📋 Model Info", expanded=False):  
 model\_info, err = call\_api("/ml/model/info")  
 if model\_info:  
 st.json(model\_info)  
 else:  
 st.warning(err or "Could not fetch model info")  
  
 col\_reload, \_ = st.columns([1, 3])  
 with col\_reload:  
 if st.button("🔄 Reload Model"):  
 result, err = call\_api("/ml/model/reload", method="POST")  
 if result:  
 st.success("Model reloaded!")  
 else:  
 st.error(err)  
  
st.markdown("---")  
  
# ─── Single Reading Prediction ─────────────────────────────────────────────────  
st.subheader("🔎 Single Reading Prediction")  
st.markdown("Enter sensor values to check if they're anomalous.")  
  
with st.form("predict\_form"):  
 col1, col2, col3, col4 = st.columns(4)  
 with col1:  
 temperature = st.number\_input("Temperature (°C)", min\_value=-50.0, max\_value=100.0, value=22.5, step=0.1)  
 with col2:  
 humidity = st.number\_input("Humidity (%)", min\_value=0.0, max\_value=100.0, value=55.0, step=0.1)  
 with col3:  
 light = st.number\_input("Light (Lux)", min\_value=0.0, max\_value=5000.0,value=300.0,step=1.0)  
 with col4:  
 voltage = st.number\_input("Voltage (V)", min\_value=0.0, max\_value=5.0, value=2.9, step=0.01)  
  
 mote\_id\_input = st.text\_input("Mote ID (optional)", value="", placeholder="e.g. 1")  
 submitted = st.form\_submit\_button("🔍 Check for Anomaly", use\_container\_width=True)  
  
if submitted:  
 if not api\_online:  
 st.error("API is not running. Cannot make predictions.")  
 else:  
 payload = {  
 "temperature": temperature,  
 "humidity": humidity,  
 "light": light,  
 "voltage": voltage,  
 }  
 if mote\_id\_input.strip():  
 payload["mote\_id"] = mote\_id\_input.strip()  
  
 with st.spinner("Running anomaly detection..."):  
 result, err = call\_api("/ml/predict/anomaly", method="POST", body=payload)  
  
 if result:  
 severity = result.get("severity", "normal")  
 score = result.get("anomaly\_score", 0)  
 is\_anomaly = result.get("is\_anomaly", False)  
  
 color\_map = {"normal": "🟢", "warning": "🟡", "critical": "🔴"}  
 emoji = color\_map.get(severity, "⚪")  
  
 res\_col1, res\_col2, res\_col3 = st.columns(3)  
 res\_col1.metric("Anomaly Score", f"{score:.4f}", delta=None)  
 res\_col2.metric("Status", f"{emoji} {severity.upper()}")  
 res\_col3.metric("Is Anomaly", "YES ⚠️" if is\_anomaly else "NO ✅")  
  
 # Score gauge  
 fig\_gauge = go.Figure(go.Indicator(  
 mode="gauge+number",  
 value=score \* 100,  
 domain={"x": [0, 1], "y": [0, 1]},  
 title={"text": "Anomaly Score (0=Normal, 100=Anomaly)"},  
 gauge={  
 "axis": {"range": [0, 100]},  
 "bar": {"color": "darkred" if is\_anomaly else "darkgreen"},  
 "steps": [  
 {"range": [0, 50], "color": "lightgreen"},  
 {"range": [50, 65], "color": "yellow"},  
 {"range": [65, 100], "color": "lightcoral"},  
 ],  
 "threshold": {"line": {"color": "red", "width": 4}, "thickness": 0.75, "value": 65},  
 },  
 ))  
 fig\_gauge.update\_layout(height=300)  
 st.plotly\_chart(fig\_gauge, use\_container\_width=True)  
 else:  
 st.error(f"Prediction failed: {err}")  
  
st.markdown("---")  
  
# ─── Batch anomaly scan ───────────────────────────────────────────────────────  
st.subheader("📊 Batch Anomaly Scan — Recent Sensor Data")  
st.markdown("Scan latest readings from InfluxDB for anomalies.")  
  
if st.button("🚀 Run Batch Scan", disabled=not api\_online):  
 # Fetch latest readings from InfluxDB  
 try:  
 from influxdb\_client import InfluxDBClient  
 client = InfluxDBClient(url=config.INFLUX\_URL, token=config.INFLUX\_TOKEN, org=config.INFLUX\_ORG)  
 query\_api = client.query\_api()  
 flux = f"""  
from(bucket: "{config.INFLUX\_BUCKET}")  
 |> range(start: -1h)  
 |> filter(fn: (r) => r["\_measurement"] == "sensor\_reading")  
 |> last()  
 |> pivot(rowKey:["\_time","mote\_id"], columnKey: ["\_field"], valueColumn: "\_value")  
"""  
 tables = query\_api.query\_data\_frame(flux, org=config.INFLUX\_ORG)  
 client.close()  
  
 if isinstance(tables, list):  
 df = pd.concat(tables, ignore\_index=True) if tables else pd.DataFrame()  
 else:  
 df = tables  
  
 if df.empty:  
 st.warning("No recent data in InfluxDB. Run the simulator first.")  
 else:  
 results = []  
 progress = st.progress(0)  
 for i, row in df.iterrows():  
 payload = {  
 "temperature": float(row.get("temperature", 22)),  
 "humidity": float(row.get("humidity", 50)),  
 "light": float(row.get("light", 100)),  
 "voltage": float(row.get("voltage", 2.9)),  
 "mote\_id": str(row.get("mote\_id", "unknown")),  
 }  
 result, \_ = call\_api("/ml/predict/anomaly", method="POST", body=payload)  
 if result:  
 results.append({  
 "mote\_id": payload["mote\_id"],  
 "temperature": payload["temperature"],  
 "humidity": payload["humidity"],  
 "light": payload["light"],  
 "voltage": payload["voltage"],  
 "anomaly\_score": result["anomaly\_score"],  
 "is\_anomaly": result["is\_anomaly"],  
 "severity": result["severity"],  
 })  
 progress.progress(min(1.0, (i + 1) / max(len(df), 1)))  
  
 if results:  
 df\_results = pd.DataFrame(results)  
 anomalies = df\_results[df\_results["is\_anomaly"]]  
  
 a\_col1, a\_col2, a\_col3 = st.columns(3)  
 a\_col1.metric("Motes Scanned", len(df\_results))  
 a\_col2.metric("Anomalies Found", len(anomalies))  
 a\_col3.metric("Anomaly Rate", f"{len(anomalies)/max(len(df\_results),1):.1%}")  
  
 # Anomaly score scatter  
 fig\_scatter = px.scatter(  
 df\_results, x="mote\_id", y="anomaly\_score",  
 color="severity",  
 color\_discrete\_map={"normal": "green", "warning": "orange", "critical": "red"},  
 title="Anomaly Scores per Mote",  
 size\_max=15,  
 )  
 fig\_scatter.add\_hline(y=0.5, line\_dash="dash", line\_color="orange", annotation\_text="Warning threshold")  
 fig\_scatter.add\_hline(y=0.65, line\_dash="dash", line\_color="red", annotation\_text="Critical threshold")  
 st.plotly\_chart(fig\_scatter, use\_container\_width=True)  
  
 # ── Full results table with colour-coded rows ──────────────  
 st.subheader("📋 All Readings")  
  
 # Row-level background colours by severity  
 def \_row\_color(row):  
 colors = {  
 "normal": "background-color: #d4edda", # green  
 "warning": "background-color: #fff3cd", # amber  
 "critical": "background-color: #f8d7da", # red  
 }  
 style = colors.get(row.get("severity", "normal"), "")  
 return [style] \* len(row)  
  
 # Add a Status emoji column at the front for quick scanning  
 display\_df = df\_results.copy()  
 display\_df.insert(0, "Status", display\_df["severity"].map({  
 "normal": "🟢 Normal",  
 "warning": "🟡 Warning",  
 "critical": "🔴 Critical",  
 }))  
 display\_df = display\_df.sort\_values("anomaly\_score", ascending=False)  
  
 st.dataframe(  
 display\_df.style.apply(\_row\_color, axis=1),  
 use\_container\_width=True,  
 )  
  
 # Keep a focused anomaly-only section below  
 if not anomalies.empty:  
 st.subheader("🚨 Anomalous Readings Only")  
 st.dataframe(  
 anomalies.sort\_values("anomaly\_score", ascending=False),  
 use\_container\_width=True,  
 )  
 except Exception as e:  
 st.error(f"Batch scan failed: {e}")

## src/app/ml/\_\_init\_\_.py

## src/app/ml/detector.py

"""Isolation Forest anomaly detector for SIEIS sensor data."""  
  
import json  
import logging  
import pickle  
from datetime import datetime  
from pathlib import Path  
from typing import Dict, Optional, Tuple  
  
import numpy as np  
import pandas as pd  
from sklearn.ensemble import IsolationForest  
from sklearn.preprocessing import StandardScaler  
from sklearn.pipeline import Pipeline  
  
from src.app import config  
  
logger = logging.getLogger(\_\_name\_\_)  
  
REGISTRY\_FILE = config.MODELS\_DIR / "model\_registry.json"  
  
  
def \_load\_registry() -> Dict:  
 if REGISTRY\_FILE.exists():  
 with open(REGISTRY\_FILE) as f:  
 return json.load(f)  
 return {"models": [], "latest": None}  
  
  
def \_save\_registry(registry: Dict):  
 config.MODELS\_DIR.mkdir(parents=True, exist\_ok=True)  
 with open(REGISTRY\_FILE, "w") as f:  
 json.dump(registry, f, indent=2)  
  
  
def train\_anomaly\_detector(  
 X: pd.DataFrame,  
 contamination: float = 0.05,  
 n\_estimators: int = 100,  
 random\_state: int = 42,  
) -> Tuple[Pipeline, Dict]:  
 """Train an Isolation Forest anomaly detector.  
   
 Analogy: Imagine a forest of decision trees. Each tree randomly  
 partitions data points. Anomalies (outliers) get isolated in fewer  
 splits than normal points — like a rotten apple that's easy to spot.  
   
 Args:  
 X: Feature matrix (temperature, humidity, light, voltage, hour, day\_of\_week)  
 contamination: Expected fraction of anomalies in data (5% default)  
 n\_estimators: Number of trees in the forest  
 random\_state: For reproducibility  
   
 Returns:  
 pipeline: Trained sklearn Pipeline (scaler + model)  
 metrics: Training statistics dict  
 """  
 logger.info(f"Training Isolation Forest: n\_samples={len(X)}, contamination={contamination}")  
  
 pipeline = Pipeline([  
 ("scaler", StandardScaler()),  
 ("model", IsolationForest(  
 n\_estimators=n\_estimators,  
 contamination=contamination,  
 random\_state=random\_state,  
 n\_jobs=-1,  
 )),  
 ])  
  
 pipeline.fit(X)  
  
 # Compute training metrics  
 predictions = pipeline.predict(X)  
 scores = pipeline.decision\_function(X)  
 n\_anomalies = int((predictions == -1).sum())  
 anomaly\_ratio = n\_anomalies / len(X)  
  
 metrics = {  
 "n\_samples": len(X),  
 "n\_features": X.shape[1],  
 "feature\_names": list(X.columns),  
 "n\_anomalies\_detected": n\_anomalies,  
 "anomaly\_ratio": round(anomaly\_ratio, 4),  
 "contamination": contamination,  
 "n\_estimators": n\_estimators,  
 "score\_mean": round(float(np.mean(scores)), 4),  
 "score\_std": round(float(np.std(scores)), 4),  
 "trained\_at": datetime.utcnow().isoformat(),  
 }  
  
 logger.info(f"Training complete: {n\_anomalies}/{len(X)} anomalies ({anomaly\_ratio:.1%})")  
 return pipeline, metrics  
  
  
def save\_model(pipeline: Pipeline, metrics: Dict, tag: Optional[str] = None) -> str:  
 """Save trained model and update model registry.  
   
 Returns the filename of the saved model.  
 """  
 config.MODELS\_DIR.mkdir(parents=True, exist\_ok=True)  
  
 timestamp = datetime.utcnow().strftime("%Y%m%d\_%H%M%S")  
 tag\_suffix = f"\_{tag}" if tag else ""  
 filename = f"anomaly\_detector\_{timestamp}{tag\_suffix}.pkl"  
 filepath = config.MODELS\_DIR / filename  
  
 artifact = {  
 "pipeline": pipeline,  
 "metrics": metrics,  
 "version": timestamp,  
 }  
  
 with open(filepath, "wb") as f:  
 pickle.dump(artifact, f)  
  
 logger.info(f"Model saved: {filepath}")  
  
 # Update registry  
 registry = \_load\_registry()  
 registry["models"].append({  
 "filename": filename,  
 "trained\_at": metrics["trained\_at"],  
 "n\_samples": metrics["n\_samples"],  
 "anomaly\_ratio": metrics["anomaly\_ratio"],  
 "features": metrics["feature\_names"],  
 })  
 registry["latest"] = filename  
 \_save\_registry(registry)  
  
 logger.info(f"Registry updated: latest={filename}")  
 return filename  
  
  
def load\_latest\_model() -> Optional[Pipeline]:  
 """Load the latest trained model from registry."""  
 registry = \_load\_registry()  
 latest = registry.get("latest")  
 if not latest:  
 logger.warning("No model in registry")  
 return None  
  
 model\_path = config.MODELS\_DIR / latest  
 if not model\_path.exists():  
 logger.error(f"Model file not found: {model\_path}")  
 return None  
  
 with open(model\_path, "rb") as f:  
 artifact = pickle.load(f)  
  
 logger.info(f"Loaded model: {latest}")  
 return artifact["pipeline"]

## src/app/ml/models/model\_registry.json

{  
 "models": [  
 {  
 "filename": "anomaly\_detector\_20260225\_041931.pkl",  
 "trained\_at": "2026-02-25T04:19:31.445233",  
 "n\_samples": 295037,  
 "anomaly\_ratio": 0.01,  
 "features": [  
 "temperature",  
 "humidity",  
 "light",  
 "voltage",  
 "hour",  
 "day\_of\_week"  
 ]  
 },  
 {  
 "filename": "anomaly\_detector\_20260225\_053331.pkl",  
 "trained\_at": "2026-02-25T05:33:31.290149",  
 "n\_samples": 295037,  
 "anomaly\_ratio": 0.01,  
 "features": [  
 "temperature",  
 "humidity",  
 "light",  
 "voltage",  
 "hour",  
 "day\_of\_week"  
 ]  
 },  
 {  
 "filename": "anomaly\_detector\_20260225\_054911.pkl",  
 "trained\_at": "2026-02-25T05:49:10.736852",  
 "n\_samples": 499638,  
 "anomaly\_ratio": 0.05,  
 "features": [  
 "temperature",  
 "humidity",  
 "light",  
 "voltage",  
 "hour",  
 "day\_of\_week"  
 ]  
 },  
 {  
 "filename": "anomaly\_detector\_20260225\_061932.pkl",  
 "trained\_at": "2026-02-25T06:19:32.665523",  
 "n\_samples": 1740246,  
 "anomaly\_ratio": 0.05,  
 "features": [  
 "temperature",  
 "humidity",  
 "light",  
 "voltage",  
 "hour",  
 "day\_of\_week"  
 ]  
 },  
 {  
 "filename": "anomaly\_detector\_20260225\_104131\_scheduled.pkl",  
 "trained\_at": "2026-02-25T10:41:31.463276",  
 "n\_samples": 1815412,  
 "anomaly\_ratio": 0.05,  
 "features": [  
 "temperature",  
 "humidity",  
 "light",  
 "voltage",  
 "hour",  
 "day\_of\_week"  
 ]  
 }  
 ],  
 "latest": "anomaly\_detector\_20260225\_104131\_scheduled.pkl"  
}

## src/app/ml/preprocessing/\_\_init\_\_.py

## src/app/ml/preprocessing/data\_prep.py

"""Data preparation for ML training — fetches from MinIO Parquet files."""  
  
import io  
import logging  
import os  
from datetime import datetime  
from typing import Optional, Tuple  
  
import pandas as pd  
import pyarrow.parquet as pq  
  
logger = logging.getLogger(\_\_name\_\_)  
  
FEATURE\_COLS = ["temperature", "humidity", "light", "voltage"]  
TIME\_FEATURE\_COLS = ["hour", "day\_of\_week"]  
ALL\_FEATURES = FEATURE\_COLS + TIME\_FEATURE\_COLS  
  
  
def \_get\_minio\_client():  
 from minio import Minio  
 from src.app import config  
 return Minio(  
 config.MINIO\_ENDPOINT,  
 access\_key=config.MINIO\_ACCESS\_KEY,  
 secret\_key=config.MINIO\_SECRET\_KEY,  
 secure=config.MINIO\_SECURE,  
 )  
  
  
def load\_parquet\_from\_minio(  
 bucket: Optional[str] = None,  
 max\_files: int = 0,  
) -> pd.DataFrame:  
 """Load Parquet files from MinIO and return a combined DataFrame.  
   
 Think of MinIO as a filing cabinet where each drawer is a day's data.  
 This function opens the drawers and reads all the files inside.  
   
 Args:  
 bucket: MinIO bucket name (defaults to config.MINIO\_BUCKET)  
 max\_files: Maximum number of Parquet files to load (0 = all files)  
   
 Returns:  
 Combined DataFrame with all sensor readings  
 """  
 from src.app import config  
 client = \_get\_minio\_client()  
 bucket = bucket or config.MINIO\_BUCKET  
  
 logger.info(f"Loading Parquet files from MinIO bucket={bucket}")  
 objects = list(client.list\_objects(bucket, recursive=True))  
 parquet\_objects = [o for o in objects if o.object\_name.endswith(".parquet")]  
  
 if not parquet\_objects:  
 logger.warning("No Parquet files found in MinIO")  
 return pd.DataFrame()  
  
 if max\_files > 0:  
 logger.info(f"Found {len(parquet\_objects)} Parquet files, loading up to {max\_files}")  
 parquet\_objects = parquet\_objects[:max\_files]  
 else:  
 logger.info(f"Found {len(parquet\_objects)} Parquet files, loading ALL")  
  
 frames = []  
 for obj in parquet\_objects:  
 try:  
 response = client.get\_object(bucket, obj.object\_name)  
 data = response.read()  
 response.close()  
 df = pd.read\_parquet(io.BytesIO(data))  
 frames.append(df)  
 except Exception as e:  
 logger.warning(f"Failed to load {obj.object\_name}: {e}")  
  
 if not frames:  
 logger.warning("All Parquet files failed to load")  
 return pd.DataFrame()  
  
 combined = pd.concat(frames, ignore\_index=True)  
 logger.info(f"Loaded {len(combined)} rows from {len(frames)} files")  
 return combined  
  
  
def load\_from\_local\_file(file\_path: str, max\_rows: int = 500\_000) -> pd.DataFrame:  
 """Load sensor data from a local text file (historical\_data.txt format).  
   
 Columns: date, time, epoch, mote\_id, temperature, humidity, light, voltage, updated\_timestamp  
 """  
 logger.info(f"Loading from local file: {file\_path}")  
 cols = ["date", "time", "epoch", "mote\_id", "temperature", "humidity", "light", "voltage", "updated\_timestamp"]  
 df = pd.read\_csv(  
 file\_path,  
 sep=r"\s+",  
 names=cols,  
 na\_values=["N/A", "nan", ""],  
 nrows=max\_rows,  
 on\_bad\_lines="skip",  
 )  
 # Combine date + time into timestamp  
 try:  
 df["timestamp"] = pd.to\_datetime(df["date"] + " " + df["time"], errors="coerce")  
 except Exception:  
 df["timestamp"] = pd.NaT  
 return df  
  
  
def prepare\_features(df: pd.DataFrame) -> Tuple[pd.DataFrame, pd.Series]:  
 """Clean and engineer features for ML training.  
   
 Like a chef prepping ingredients — this removes bad data,  
 adds time-based features, and returns a clean feature matrix.  
   
 Returns:  
 X: Feature DataFrame (ready for sklearn)  
 mote\_ids: Series of mote IDs aligned with X  
 """  
 df = df.copy()  
  
 # Ensure sensor columns are numeric  
 for col in FEATURE\_COLS:  
 if col in df.columns:  
 df[col] = pd.to\_numeric(df[col], errors="coerce")  
  
 # Drop rows with all sensor values missing  
 df = df.dropna(subset=FEATURE\_COLS, how="all")  
  
 # Parse timestamp columns from strings if needed  
 # (consumer writes updated\_timestamp as ISO strings in Parquet)  
 for ts\_col in ("updated\_timestamp", "timestamp"):  
 if ts\_col in df.columns and not pd.api.types.is\_datetime64\_any\_dtype(df[ts\_col]):  
 df[ts\_col] = pd.to\_datetime(df[ts\_col], utc=True, errors="coerce")  
  
 # Add time features — prefer updated\_timestamp (real-time mapped), fall back to timestamp  
 ts\_series = None  
 for ts\_col in ("updated\_timestamp", "timestamp"):  
 if ts\_col in df.columns and pd.api.types.is\_datetime64\_any\_dtype(df[ts\_col]):  
 ts\_series = df[ts\_col]  
 break  
  
 if ts\_series is not None:  
 df["hour"] = ts\_series.dt.hour  
 df["day\_of\_week"] = ts\_series.dt.dayofweek  
 else:  
 df["hour"] = 12 # fallback  
 df["day\_of\_week"] = 0  
  
 # Keep only valid ranges (sensor physics bounds)  
 df = df[df["temperature"].between(-10, 80) | df["temperature"].isna()]  
 df = df[df["humidity"].between(0, 100) | df["humidity"].isna()]  
 df = df[df["light"].between(0, 3000) | df["light"].isna()]  
 df = df[df["voltage"].between(0, 5) | df["voltage"].isna()]  
  
 available\_features = [c for c in ALL\_FEATURES if c in df.columns]  
 X = df[available\_features].copy()  
  
 # Fill remaining NaN with column medians  
 X = X.fillna(X.median(numeric\_only=True))  
  
 mote\_ids = df.get("mote\_id", pd.Series(["unknown"] \* len(df)))  
  
 logger.info(f"Prepared feature matrix: {X.shape}, features={available\_features}")  
 return X, mote\_ids

## src/app/scheduler/\_\_init\_\_.py

# SIEIS Scheduler package

## src/app/scheduler/jobs.py

"""  
SIEIS Scheduler Jobs  
====================  
Two daily jobs that automate the full pipeline:  
  
 Job A 00:00 UTC — Remap incremental\_data.txt to today's dates  
 → Restart simulator so it emits fresh data  
 Job B 02:00 UTC — Retrain IsolationForest on yesterday's MinIO Parquet files  
 → Hot-reload the FastAPI model (no restart needed)  
  
Analogy  
-------  
Think of this like a newspaper printing plant:  
 - Job A is the night-shift that updates the "today's date" stamp on the press  
 and restarts the press so it prints the right edition.  
 - Job B is the editor-in-chief who reviews all of yesterday's stories,  
 refines the spam filter (anomaly model), and pushes it live.  
"""  
  
import logging  
import os  
import sys  
from datetime import date, timedelta  
from pathlib import Path  
  
import requests  
  
logger = logging.getLogger(\_\_name\_\_)  
  
# ── Environment config ────────────────────────────────────────────────────────  
API\_RELOAD\_URL = os.getenv(  
 "API\_RELOAD\_URL", "http://sieis-api:8000/api/v1/ml/model/reload"  
)  
SIMULATOR\_CONTAINER = os.getenv("SIMULATOR\_CONTAINER", "sieis-simulator")  
INCR\_DATA\_PATH = Path(  
 os.getenv("INCR\_DATA\_PATH", "/app/data/processed/incremental\_data.txt")  
)  
  
  
# ── Helpers ───────────────────────────────────────────────────────────────────  
  
def \_restart\_simulator() -> bool:  
 """Restart the simulator Docker container via the Docker Python SDK.  
  
 Returns True on success, False on failure.  
  
 The Docker socket (/var/run/docker.sock) must be mounted into this  
 container (see docker-compose.yml).  
 """  
 try:  
 import docker # docker>=6.1.0  
 client = docker.from\_env()  
 container = client.containers.get(SIMULATOR\_CONTAINER)  
 container.restart(timeout=30)  
 logger.info("Simulator container '%s' restarted successfully", SIMULATOR\_CONTAINER)  
 return True  
 except Exception:  
 logger.exception(  
 "Failed to restart simulator container '%s'. "  
 "Check that /var/run/docker.sock is mounted and the container name is correct.",  
 SIMULATOR\_CONTAINER,  
 )  
 return False  
  
  
def \_reload\_api\_model() -> bool:  
 """POST to the FastAPI /ml/model/reload endpoint to hot-swap the model.  
  
 Returns True on success, False on failure.  
 No container restart required — the API picks up the latest .pkl from disk.  
 """  
 try:  
 resp = requests.post(API\_RELOAD\_URL, timeout=15)  
 resp.raise\_for\_status()  
 payload = resp.json()  
 logger.info("API model reloaded: %s", payload)  
 return True  
 except requests.exceptions.ConnectionError:  
 logger.error(  
 "Could not reach API at %s. Is sieis-api running?", API\_RELOAD\_URL  
 )  
 return False  
 except Exception:  
 logger.exception("Unexpected error calling API reload endpoint")  
 return False  
  
  
# ── Job A: Daily Data Refresh ─────────────────────────────────────────────────  
def data\_exists\_for\_today() -> bool:  
 """  
 Check if there is data for today.  
 You should implement this function to check your data source (e.g., MinIO, local file, DB).  
 """  
 from src.app.ml.preprocessing.data\_prep import load\_parquet\_from\_minio  
 df = load\_parquet\_from\_minio()  
 today\_str = date.today().isoformat()  
 # Adjust the column name as per your data, e.g., 'date' or 'timestamp'  
 return not df[df['date'] == today\_str].empty  
  
def remap\_and\_restart() -> None:  
 """  
 Modified Job A — runs at 00:00 UTC daily.  
 Only restarts the simulator if today's data exists. No remapping.  
 """  
 logger.info("Restarting simulator container '%s'", SIMULATOR\_CONTAINER)  
 ok = \_restart\_simulator()  
 status = "SUCCESS" if ok else "FAILED (check logs)"  
 logger.info("Simulator restart: %s", status)  
  
# ── Job B: Daily Model Retrain ────────────────────────────────────────────────  
  
def retrain\_and\_reload() -> None:  
 """  
 Job B — runs at 02:00 UTC daily.  
  
 Step 1: Load yesterday's sensor data from MinIO Parquet archive.  
 Falls back to last 30 days of Parquet if yesterday alone is sparse.  
  
 Step 2: Prepare feature matrix: temperature, humidity, light, voltage,  
 hour-of-day, day-of-week.  
  
 Step 3: Train a new IsolationForest model and save it as:  
 anomaly\_detector\_YYYYMMDD\_HHMMSS\_scheduled.pkl  
  
 Step 4: POST to FastAPI /ml/model/reload — the API hot-swaps its  
 in-memory pipeline without any container restart.  
  
 Analogy: Like a bakery that checks what sold best yesterday, adjusts the  
 recipe overnight, and opens in the morning with a fresher product —  
 without closing the shop.  
 """  
 logger.info("Loading Parquet data from MinIO (last 3 days)...")  
 try:  
 from src.app.ml.preprocessing.data\_prep import (  
 load\_parquet\_from\_minio,  
 prepare\_features,  
 )  
 from datetime import date, timedelta  
  
 df = load\_parquet\_from\_minio()  
  
 today = date.today()  
 recent\_dates = [(today - timedelta(days=i)).isoformat() for i in range(0, 3)]  
 if 'date' in df.columns:  
 df\_recent = df[df['date'].isin(recent\_dates)]  
 else:  
 logger.warning("DataFrame does not have a 'date' column. Using all data.")  
 df\_recent = df  
  
 if df\_recent.empty:  
 logger.warning(  
 "No Parquet data found in MinIO for last 3 days. "  
 "Retrain skipped — existing model remains active."  
 )  
 return  
  
 logger.info("Loaded %d rows for retraining", len(df\_recent))  
 except Exception:  
 logger.exception("MinIO data load failed — retrain aborted")  
 return  
  
 try:  
 X, mote\_ids = prepare\_features(df\_recent)  
 if X.empty or len(X) < 100:  
 logger.warning(  
 "Feature matrix too small (%d rows) for reliable training. "  
 "Need at least 100 rows. Retrain skipped.",  
 len(X),  
 )  
 return  
 logger.info("Feature matrix shape: %s", X.shape)  
 except Exception:  
 logger.exception("Feature preparation failed — retrain aborted")  
 return  
  
 # -- Step 3: Train and save model ----------------------------------------  
 logger.info("[3/4] Training IsolationForest...")  
 try:  
 from src.app.ml.detector import train\_anomaly\_detector, save\_model # noqa: PLC0415  
  
 pipeline, metrics = train\_anomaly\_detector(X)  
 logger.info(  
 "Training complete: %d anomalies / %d samples (%.1f%%)",  
 metrics["n\_anomalies\_detected"],  
 metrics["n\_samples"],  
 metrics["anomaly\_ratio"] \* 100,  
 )  
  
 filename = save\_model(pipeline, metrics, tag="scheduled")  
 logger.info("Model saved: %s", filename)  
 except Exception:  
 logger.exception("Model training/save failed — retrain aborted")  
 return  
  
 # -- Step 4: Hot-reload API model ----------------------------------------  
 logger.info("[4/4] Reloading API model...")  
 ok = \_reload\_api\_model()  
 status = "SUCCESS" if ok else "FAILED — API still uses previous model"  
 logger.info("JOB B complete — API reload: %s", status)  
 logger.info("=" \* 60)

## src/app/scheduler/main.py

"""  
SIEIS Scheduler Entry Point  
============================  
Starts APScheduler with two daily cron jobs:  
  
 Job A 00:00 UTC remap\_and\_restart — refresh incremental data + restart simulator  
 Job B 02:00 UTC retrain\_and\_reload — retrain anomaly model + hot-reload API  
  
Environment Variables (all optional, with defaults):  
 SCHEDULER\_TIMEZONE UTC  
 JOB\_A\_HOUR 0 (midnight UTC)  
 JOB\_A\_MINUTE 0  
 JOB\_B\_HOUR 2 (2 AM UTC)  
 JOB\_B\_MINUTE 0  
 RUN\_JOBS\_ON\_START false set "true" to fire both jobs immediately at startup  
 (useful for smoke-testing without waiting for midnight)  
  
Usage:  
 docker-compose up scheduler # normal operation  
 RUN\_JOBS\_ON\_START=true docker-compose up scheduler # immediate test run  
"""  
  
import logging  
import os  
import sys  
from datetime import datetime  
from pathlib import Path  
  
# Ensure project root is on path when run inside Docker (/app)  
\_project\_root = Path(\_\_file\_\_).parents[3] # src/app/scheduler -> project root  
if str(\_project\_root) not in sys.path:  
 sys.path.insert(0, str(\_project\_root))  
  
from apscheduler.schedulers.blocking import BlockingScheduler  
from apscheduler.triggers.cron import CronTrigger  
from apscheduler.events import EVENT\_JOB\_ERROR, EVENT\_JOB\_EXECUTED  
  
from src.app.scheduler.jobs import remap\_and\_restart, retrain\_and\_reload  
  
logging.basicConfig(  
 level=logging.INFO,  
 format="%(asctime)s [%(levelname)s] %(name)s — %(message)s",  
 datefmt="%Y-%m-%d %H:%M:%S",  
)  
logger = logging.getLogger(\_\_name\_\_)  
  
# ── Config from environment ───────────────────────────────────────────────────  
TIMEZONE = os.getenv("SCHEDULER\_TIMEZONE", "UTC")  
JOB\_A\_HOUR = int(os.getenv("JOB\_A\_HOUR", "0"))  
JOB\_A\_MINUTE = int(os.getenv("JOB\_A\_MINUTE", "0"))  
JOB\_B\_HOUR = int(os.getenv("JOB\_B\_HOUR", "2"))  
JOB\_B\_MINUTE = int(os.getenv("JOB\_B\_MINUTE", "0"))  
RUN\_JOBS\_ON\_START = os.getenv("RUN\_JOBS\_ON\_START", "false").lower() == "true"  
  
  
# ── Event listener for job success / failure alerts ──────────────────────────  
  
def \_job\_listener(event):  
 """Log job outcomes clearly — makes docker logs easy to grep."""  
 job = event.job\_id  
 if event.exception:  
 logger.error("JOB FAILED [%s]: %s", job, event.exception)  
 else:  
 logger.info("JOB SUCCESS [%s]", job)  
  
  
# ── Main ─────────────────────────────────────────────────────────────────────  
  
def main():  
 logger.info("=" \* 60)  
 logger.info("SIEIS Scheduler starting")  
 logger.info(" Timezone : %s", TIMEZONE)  
 logger.info(" Job A : %02d:%02d remap\_and\_restart", JOB\_A\_HOUR, JOB\_A\_MINUTE)  
 logger.info(" Job B : %02d:%02d retrain\_and\_reload", JOB\_B\_HOUR, JOB\_B\_MINUTE)  
 logger.info(" Immediate: %s", RUN\_JOBS\_ON\_START)  
 logger.info("=" \* 60)  
  
 scheduler = BlockingScheduler(timezone=TIMEZONE)  
 scheduler.add\_listener(\_job\_listener, EVENT\_JOB\_EXECUTED | EVENT\_JOB\_ERROR)  
  
 # ── Job A: Daily data refresh ──────────────────────────────────────────  
 scheduler.add\_job(  
 remap\_and\_restart,  
 trigger=CronTrigger(hour=JOB\_A\_HOUR, minute=JOB\_A\_MINUTE, timezone=TIMEZONE),  
 id="job\_a\_data\_refresh",  
 name="Daily Data Refresh (remap + restart simulator)",  
 max\_instances=1,  
 coalesce=True, # if missed, run once (not multiple catch-ups)  
 misfire\_grace\_time=300, # 5-min grace window before marking as missed  
 )  
  
 # ── Job B: Daily model retrain ─────────────────────────────────────────  
 scheduler.add\_job(  
 retrain\_and\_reload,  
 trigger=CronTrigger(hour=JOB\_B\_HOUR, minute=JOB\_B\_MINUTE, timezone=TIMEZONE),  
 id="job\_b\_model\_retrain",  
 name="Daily Model Retrain (train + reload API)",  
 max\_instances=1,  
 coalesce=True,  
 misfire\_grace\_time=600, # 10-min grace (training can be slow)  
 )  
  
 # ── Immediate run for smoke-testing ────────────────────────────────────  
 if RUN\_JOBS\_ON\_START:  
 logger.info("RUN\_JOBS\_ON\_START=true — triggering both jobs now for testing")  
 scheduler.add\_job(  
 remap\_and\_restart,  
 id="job\_a\_immediate",  
 name="Immediate Test: remap\_and\_restart",  
 )  
 scheduler.add\_job(  
 retrain\_and\_reload,  
 id="job\_b\_immediate",  
 name="Immediate Test: retrain\_and\_reload",  
 )  
  
 # ── Start (blocks forever) ─────────────────────────────────────────────  
 logger.info("Scheduler running. Next runs:")  
 try:  
 scheduler.start()  
 except (KeyboardInterrupt, SystemExit):  
 logger.info("Scheduler stopped gracefully")  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## src/app/simulator/\_\_init\_\_.py

"""Simulator package for streaming Intel Lab sensor data."""

## src/app/simulator/data\_loader.py

"""Load and clean Intel Lab sensor data for simulation."""  
  
import pandas as pd  
import logging  
from datetime import datetime  
from typing import Dict, Optional, Tuple  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def load\_data\_loader(data\_path: str, mote\_locs\_path: str, filter\_today\_only: bool = True) -> Tuple[Dict[int, pd.DataFrame], pd.DataFrame]:  
 """  
 Load Intel Lab sensor data and mote locations.  
   
 Args:  
 data\_path: Path to data file (8-column legacy or 9-column with updated\_timestamp)  
 mote\_locs\_path: Path to mote\_locs.txt file  
 filter\_today\_only: If True, only load records where updated\_timestamp is TODAY  
   
 Returns:  
 Tuple of (mote\_data\_dict, mote\_locations\_df)  
 - mote\_data\_dict: {mote\_id: DataFrame with sensor readings}  
 - mote\_locations\_df: DataFrame with mote locations  
 """  
   
 logger.info(f"Loading sensor data from {data\_path}")  
   
 # Load sensor data  
 # File columns: date time epoch moteid temperature humidity light voltage [updated\_timestamp]  
 # 9th column (updated\_timestamp) is optional for backward compatibility  
 # Note: Only specify dtype for first 8 columns, let pandas infer the 9th (if present)  
 df = pd.read\_csv(  
 data\_path,  
 sep=r'\s+',  
 header=None,  
 names=['date', 'time', 'epoch', 'moteid', 'temperature', 'humidity', 'light', 'voltage', 'updated\_timestamp'],  
 na\_values=['?']  
 )  
   
 # Ensure proper dtypes for numeric columns  
 df['epoch'] = pd.to\_numeric(df['epoch'], errors='coerce')  
 df['moteid'] = pd.to\_numeric(df['moteid'], errors='coerce')  
 df['temperature'] = pd.to\_numeric(df['temperature'], errors='coerce')  
 df['humidity'] = pd.to\_numeric(df['humidity'], errors='coerce')  
 df['light'] = pd.to\_numeric(df['light'], errors='coerce')  
 df['voltage'] = pd.to\_numeric(df['voltage'], errors='coerce')  
   
 raw\_count = len(df)  
 logger.info(f"Loaded {raw\_count:,} total records")  
  
 # ── Row validation ────────────────────────────────────────────────────  
 # Shifted rows: when a source line has fewer fields than expected, pandas  
 # shifts all values left. The symptom is an ISO-8601 timestamp string  
 # landing in the `voltage` column and `updated\_timestamp` becoming NaN.  
 # Detect these early by coercing numeric columns and flagging NaN moteids.  
  
 # Guard 1 — moteid must be numeric (already coerced above; NaN rows dropped here)  
 non\_numeric\_mote = df['moteid'].isna().sum()  
 if non\_numeric\_mote:  
 logger.warning(  
 f"Row validation: dropped {non\_numeric\_mote:,} rows with non-numeric moteid"  
 )  
 df = df.dropna(subset=['moteid'])  
  
 # Guard 2 — moteid must be within the Intel Lab sensor range (1–100)  
 # Rows outside this range are artefacts of column-shift parse errors.  
 MOTE\_ID\_MIN, MOTE\_ID\_MAX = 1, 100  
 out\_of\_range = ~df['moteid'].between(MOTE\_ID\_MIN, MOTE\_ID\_MAX)  
 if out\_of\_range.any():  
 logger.warning(  
 f"Row validation: dropped {out\_of\_range.sum():,} rows with "  
 f"moteid outside [{MOTE\_ID\_MIN}, {MOTE\_ID\_MAX}] "  
 f"(saw values: {sorted(df.loc[out\_of\_range, 'moteid'].unique().tolist()[:10])})"  
 )  
 df = df[~out\_of\_range]  
  
 total\_dropped = raw\_count - len(df)  
 if total\_dropped:  
 logger.info(  
 f"Row validation complete: {total\_dropped:,} malformed rows removed "  
 f"({total\_dropped / raw\_count \* 100:.2f}% of input), "  
 f"{len(df):,} clean rows retained"  
 )  
  
 # Combine date + time into a single timestamp column (original 2004 timestamps)  
 df['timestamp'] = pd.to\_datetime(  
 df['date'].astype(str) + ' ' + df['time'].astype(str), format='%Y-%m-%d %H:%M:%S.%f', errors='coerce'  
 )  
  
 # Drop rows where timestamp could not be parsed  
 df = df.dropna(subset=['timestamp'])  
  
 # Parse updated\_timestamp if present (pre-mapped to current year)  
 if 'updated\_timestamp' in df.columns and df['updated\_timestamp'].notna().any():  
 df['updated\_timestamp'] = pd.to\_datetime(df['updated\_timestamp'], errors='coerce')  
 logger.info("Found updated\_timestamp column in data file")  
  
 # Guard 3 — drop rows whose updated\_timestamp failed to parse.  
 # In 9-column mode these are the remaining shifted rows: their voltage  
 # column holds a timestamp string, so `updated\_timestamp` is NaN.  
 bad\_ts = df['updated\_timestamp'].isna()  
 if bad\_ts.any():  
 logger.warning(  
 f"Row validation: dropped {bad\_ts.sum():,} rows with "  
 "unparseable updated\_timestamp (likely shifted-column rows)"  
 )  
 df = df[~bad\_ts]  
  
 # FILTER: Only keep records for TODAY if requested  
 if filter\_today\_only:  
 today = datetime.now().date()  
 initial\_count = len(df)  
 df = df[df['updated\_timestamp'].dt.date == today].copy()  
 logger.info(f"Filtered to {len(df):,} records for today ({today}) from {initial\_count:,} total records")  
  
 if len(df) == 0:  
 logger.warning(f"⚠️ No records found for today ({today})!")  
 logger.warning(" This might mean:")  
 logger.warning(" 1. The transformation was run on a different date")  
 logger.warning(" 2. All today's data was filtered as future timestamps")  
 logger.warning(" 3. The realtime\_data.txt file needs to be regenerated")  
 else:  
 logger.info("No updated\_timestamp column found - using legacy 8-column format")  
  
 # Convert moteid to int (moteid is already validated and non-null above)  
 df['moteid'] = df['moteid'].astype(int)  
 # Drop rows with null temperature or humidity  
 df = df.dropna(subset=['temperature', 'humidity'])  
   
 # Fill null light with 0  
 df['light'] = df['light'].fillna(0.0)  
   
 # Forward fill voltage per mote to keep continuity in streams  
 df = df.sort\_values(['moteid', 'timestamp'])  
 df['voltage'] = df.groupby('moteid')['voltage'].ffill()  
   
 # Fill any remaining null voltage with backward fill (for first readings)  
 df['voltage'] = df['voltage'].bfill()  
   
 # Split by mote ID for per-sensor simulation  
 mote\_data\_dict = {}  
 unique\_motes = df['moteid'].unique()  
 logger.info(f"Processing {len(unique\_motes)} unique motes")  
   
 for mote\_id in unique\_motes:  
 mote\_df = df[df['moteid'] == mote\_id].copy()  
 # Sort by timestamp  
 mote\_df = mote\_df.sort\_values('timestamp').reset\_index(drop=True)  
 mote\_data\_dict[mote\_id] = mote\_df  
 logger.debug(f" Mote {mote\_id}: {len(mote\_df)} records")  
   
 # Load mote locations  
 mote\_locs\_df = pd.read\_csv(  
 mote\_locs\_path,  
 sep=r'\s+',  
 header=None,  
 names=['moteid', 'x', 'y'],  
 dtype={'moteid': int, 'x': float, 'y': float}  
 )  
   
 return mote\_data\_dict, mote\_locs\_df  
  
  
def get\_mote\_data(data\_path: str, mote\_locs\_path: str, mote\_id: int) -> pd.DataFrame:  
 """  
 Get sensor data for a specific mote.  
   
 Args:  
 data\_path: Path to data.txt file  
 mote\_locs\_path: Path to mote\_locs.txt file  
 mote\_id: Mote ID to retrieve  
   
 Returns:  
 DataFrame with sensor readings for the mote  
 """  
 mote\_data\_dict, \_ = load\_data\_loader(data\_path, mote\_locs\_path)  
 return mote\_data\_dict.get(mote\_id, pd.DataFrame())  
  
  
def get\_mote\_location(mote\_locs\_path: str, mote\_id: int) -> Optional[Tuple[float, float]]:  
 """  
 Get (x, y) location for a mote.  
   
 Args:  
 mote\_locs\_path: Path to mote\_locs.txt file  
 mote\_id: Mote ID to retrieve  
   
 Returns:  
 Tuple of (x, y) coordinates  
 """  
 mote\_locs\_df = pd.read\_csv(  
 mote\_locs\_path,  
 sep=r'\s+',  
 header=None,  
 names=['moteid', 'x', 'y'],  
 dtype={'moteid': int, 'x': float, 'y': float}  
 )  
   
 loc = mote\_locs\_df[mote\_locs\_df['moteid'] == mote\_id]  
 if len(loc) > 0:  
 return (loc.iloc[0]['x'], loc.iloc[0]['y'])  
 return None

## src/app/simulator/emitter.py

"""Emit per-mote readings to Kafka with time compression."""  
  
import logging  
import time  
from typing import Optional  
from src.app.config import YEAR\_OFFSET  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def emit\_mote(mote\_id: int, df, producer, speed\_factor: float = 100.0, stop\_event: Optional[object] = None) -> None:  
 """Emit rows for a single mote DataFrame to Kafka using the provided producer.  
  
 - `df` is expected to contain columns: `timestamp`, `epoch`, `temperature`,  
 `humidity`, `light`, `voltage`, and optionally `updated\_timestamp` (pre-mapped).  
 - `speed\_factor` compresses real-time delays (delay\_seconds = delta / speed\_factor).  
 - `stop\_event` (optional) should be an object with `is\_set()` method to allow graceful shutdown.  
 """  
 prev\_ts = None  
 for \_, row in df.iterrows():  
 if stop\_event is not None and getattr(stop\_event, "is\_set", lambda: False)():  
 logger.info("Stop event set for mote %s, exiting emitter", mote\_id)  
 break  
  
 ts = row["timestamp"]  
 if prev\_ts is not None:  
 delta = (ts - prev\_ts).total\_seconds()  
 if delta > 0:  
 # Sleep scaled by speed\_factor to simulate real-time pacing.  
 delay = float(delta) / float(speed\_factor)  
 time.sleep(delay)  
  
 # Use pre-calculated updated\_timestamp if available, otherwise calculate at runtime  
 import pandas as pd  
 if 'updated\_timestamp' in row.index and pd.notna(row.get('updated\_timestamp')):  
 # Use pre-mapped timestamp from data file (preferred for accuracy)  
 # Convert pandas Timestamp to datetime if needed  
 updated\_ts = pd.to\_datetime(row['updated\_timestamp']).to\_pydatetime()  
 else:  
 # Fallback: Calculate updated timestamp mapping 2004 data to current year  
 # Handle leap year edge case (Feb 29 in leap year -> Feb 28 in non-leap year)  
 try:  
 updated\_ts = ts.replace(year=ts.year + YEAR\_OFFSET)  
 except ValueError:  
 # Feb 29 in leap year 2004 -> Feb 28 in non-leap year 2025  
 updated\_ts = ts.replace(year=ts.year + YEAR\_OFFSET, day=28)  
  
 msg = {  
 "mote\_id": int(mote\_id),  
 "timestamp": ts.isoformat(),  
 "updated\_timestamp": updated\_ts.isoformat(),  
 "original\_timestamp": ts.strftime("%Y-%m-%dT%H:%M:%S.%f"),  
 "temperature": float(row.get("temperature")) if row.get("temperature") is not None else None,  
 "humidity": float(row.get("humidity")) if row.get("humidity") is not None else None,  
 "light": float(row.get("light")) if row.get("light") is not None else None,  
 "voltage": float(row.get("voltage")) if row.get("voltage") is not None else None,  
 "epoch": int(row.get("epoch")) if row.get("epoch") is not None else None,  
 }  
  
 try:  
 producer.send(msg, key=mote\_id)  
 except Exception:  
 logger.exception("Emitter failed sending message for mote %s", mote\_id)  
  
 prev\_ts = ts

## src/app/simulator/main.py

"""Simulator entry point to run the orchestrator in the foreground."""  
  
import logging  
import time  
from pathlib import Path  
import sys  
  
# Add project root to sys.path so imports work when run directly  
\_project\_root = Path(\_\_file\_\_).parents[3]  
if str(\_project\_root) not in sys.path:  
 sys.path.insert(0, str(\_project\_root))  
  
from src.app.simulator.orchestrator import Orchestrator  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
def main():  
 logging.basicConfig(level=logging.INFO)  
 orch = Orchestrator()  
 try:  
 orch.start()  
 # Keep main thread alive while child threads run  
 while True:  
 time.sleep(1.0)  
 except KeyboardInterrupt:  
 logger.info("KeyboardInterrupt received — stopping")  
 orch.stop()  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## src/app/simulator/orchestrator.py

"""Orchestrate per-mote emitter threads and producer lifecycle."""  
  
import logging  
import threading  
from typing import Optional  
  
from src.app.config import KAFKA\_BROKER, KAFKA\_TOPIC, SPEED\_FACTOR, DATA\_PATH, MOTE\_LOCS\_PATH, FILTER\_TODAY\_ONLY  
from src.app.simulator.data\_loader import load\_data\_loader  
from src.app.simulator.producer import Producer  
from src.app.simulator.emitter import emit\_mote  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
class Orchestrator:  
 """Start per-mote emitters and manage graceful shutdown."""  
 def \_\_init\_\_(self, broker: str = KAFKA\_BROKER, topic: str = KAFKA\_TOPIC, max\_motes: Optional[int] = None, filter\_today\_only: Optional[bool] = None):  
 self.producer = Producer(broker=broker, topic=topic)  
 # Use provided filter parameter, otherwise default to config value  
 filter\_param = filter\_today\_only if filter\_today\_only is not None else FILTER\_TODAY\_ONLY  
 self.mote\_data, \_ = load\_data\_loader(DATA\_PATH, MOTE\_LOCS\_PATH, filter\_today\_only=filter\_param)  
 self.max\_motes = max\_motes  
 self.threads = []  
 self.stop\_event = threading.Event()  
  
 def start(self):  
 mote\_ids = list(self.mote\_data.keys())  
 if self.max\_motes:  
 mote\_ids = mote\_ids[: self.max\_motes]  
  
 logger.info("Starting orchestrator for %d motes", len(mote\_ids))  
 for mote\_id in mote\_ids:  
 # One thread per mote keeps each sensor stream independent.  
 t = threading.Thread(target=self.\_run\_mote, args=(mote\_id,))  
 t.daemon = True  
 t.start()  
 self.threads.append(t)  
  
 def \_run\_mote(self, mote\_id: int):  
 df = self.mote\_data[mote\_id]  
 try:  
 emit\_mote(mote\_id, df, self.producer, SPEED\_FACTOR, stop\_event=self.stop\_event)  
 except Exception:  
 logger.exception("Orchestrator error for mote %s", mote\_id)  
  
 def stop(self):  
 logger.info("Stopping orchestrator: signalling stop to emitters")  
 self.stop\_event.set()  
 for t in self.threads:  
 t.join(timeout=1.0)  
 logger.info("Flushing producer and closing")  
 self.producer.flush()  
 self.producer.close()

## src/app/simulator/producer.py

"""Kafka producer wrapper with JSON serialization and safe send behavior."""  
  
import json  
import logging  
from typing import Any, Optional  
  
from kafka import KafkaProducer  
  
logger = logging.getLogger(\_\_name\_\_)  
  
  
class Producer:  
 """Simple Kafka producer wrapper using kafka-python.  
  
 If the broker is unavailable, sends are logged and skipped.  
 """  
  
 def \_\_init\_\_(self, broker: str = "localhost:9092", topic: str = "sensor\_readings"):  
 self.broker = broker  
 self.topic = topic  
 self.\_producer: Optional[KafkaProducer] = None  
 try:  
 self.\_producer = KafkaProducer(  
 bootstrap\_servers=[broker],  
 value\_serializer=lambda v: json.dumps(v).encode("utf-8"),  
 key\_serializer=lambda k: str(k).encode("utf-8") if k is not None else None,  
 retries=3,  
 acks=1,  
 )  
 logger.info("Connected Kafka producer to %s", broker)  
 except Exception as exc: # pragma: no cover - runtime environment dependent  
 logger.warning("Could not initialize KafkaProducer (%s); sending will be no-op", exc)  
 self.\_producer = None  
  
 def send(self, value: Any, key: Any = None) -> None:  
 """Send a message to the configured topic. Synchronous by default.  
  
 This method will log and return if the producer was not initialized.  
 """  
 if not self.\_producer:  
 logger.debug("Producer not initialized — skipping send: %s", value)  
 return  
  
 try:  
 fut = self.\_producer.send(self.topic, key=key, value=value)  
 # Block until the broker acks the message.  
 fut.get(timeout=10)  
 except Exception:  
 logger.exception("Failed to send message to Kafka: %s", value)  
  
 def flush(self) -> None:  
 if self.\_producer:  
 try:  
 self.\_producer.flush()  
 except Exception:  
 logger.exception("Kafka flush failed")  
  
 def close(self) -> None:  
 if self.\_producer:  
 try:  
 self.\_producer.close()  
 except Exception:  
 logger.exception("Kafka close failed")

## tests/run\_all\_tests.py

"""Master test runner for all container tests and full pipeline."""  
  
import sys  
import subprocess  
from pathlib import Path  
  
  
def run\_test(test\_file):  
 """Run a single test file and return result."""  
 print(f"\n{'='\*80}")  
 print(f"Running: {test\_file.name}")  
 print('='\*80)  
   
 result = subprocess.run(  
 [sys.executable, str(test\_file)],  
 capture\_output=False  
 )  
   
 return result.returncode == 0  
  
  
def main():  
 """Run all container tests and full pipeline test."""  
 tests\_dir = Path(\_\_file\_\_).parent  
   
 tests = [  
 tests\_dir / "test\_container\_redpanda.py",  
 tests\_dir / "test\_container\_influxdb.py",  
 tests\_dir / "test\_container\_minio.py",  
 tests\_dir / "test\_full\_pipeline.py"  
 ]  
   
 print("\n" + "🧪" \* 40)  
 print("MASTER TEST SUITE - ALL CONTAINERS + FULL PIPELINE")  
 print("🧪" \* 40)  
 print("\nThis will test:")  
 print(" 1. Redpanda (Kafka) container")  
 print(" 2. InfluxDB 2.7 container")  
 print(" 3. MinIO container")  
 print(" 4. Full end-to-end data pipeline")  
   
 results = []  
 for test\_file in tests:  
 if test\_file.exists():  
 passed = run\_test(test\_file)  
 results.append((test\_file.name, passed))  
 else:  
 print(f"\n⚠️ Test file not found: {test\_file}")  
 results.append((test\_file.name, False))  
   
 # Final summary  
 print("\n" + "="\*80)  
 print("FINAL SUMMARY - ALL TESTS")  
 print("="\*80)  
   
 for test\_name, passed in results:  
 status = "✅ PASS" if passed else "❌ FAIL"  
 print(f"{status}: {test\_name}")  
   
 passed\_count = sum(1 for \_, p in results if p)  
 total\_count = len(results)  
   
 print(f"\n📊 Overall: {passed\_count}/{total\_count} test suites passed")  
   
 if passed\_count == total\_count:  
 print("\n🎉 🎉 🎉 ALL TESTS PASSED! 🎉 🎉 🎉")  
 print("\n✅ All containers are operational")  
 print("✅ Full data pipeline is working")  
 print("✅ Dual-write pattern (InfluxDB + MinIO) verified")  
 print("\nSystem is fully operational and ready for production use!")  
 return 0  
 else:  
 print(f"\n⚠️ {total\_count - passed\_count} test suite(s) failed")  
 print("\n📋 Next steps:")  
 print(" 1. Review failed test output above")  
 print(" 2. Check Docker containers: docker ps")  
 print(" 3. Check logs: docker-compose logs -f")  
 print(" 4. Restart services if needed: docker-compose restart")  
 return 1  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 sys.exit(main())

## tests/test\_container\_influxdb.py

"""Test InfluxDB 2.7 container functionality."""  
  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
import time  
from datetime import datetime, timedelta  
from influxdb\_client import InfluxDBClient, Point, WritePrecision  
from influxdb\_client.client.write\_api import SYNCHRONOUS  
from tests.test\_config import INFLUX\_URL, INFLUX\_TOKEN, INFLUX\_ORG, INFLUX\_BUCKET  
  
  
def test\_influxdb\_container():  
 """Test 1: Verify InfluxDB container is running and accessible."""  
 print("\n" + "="\*80)  
 print("TEST 1: InfluxDB Container Health Check")  
 print("="\*80)  
   
 try:  
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG,  
 timeout=10000  
 )  
   
 health = client.health()  
 print(f"✅ Connected to InfluxDB at {INFLUX\_URL}")  
 print(f"✅ Health status: {health.status}")  
 print(f"✅ Version: {health.version}")  
   
 orgs\_api = client.organizations\_api()  
 orgs = orgs\_api.find\_organizations()  
 org\_names = [org.name for org in orgs]  
 print(f"✅ Organizations: {org\_names}")  
   
 if INFLUX\_ORG in org\_names:  
 print(f"✅ Target organization found: {INFLUX\_ORG}")  
   
 client.close()  
 return True  
 except Exception as e:  
 print(f"❌ Failed to connect to InfluxDB: {e}")  
 return False  
  
  
def test\_bucket\_access():  
 """Test 2: Verify bucket exists and is accessible."""  
 print("\n" + "="\*80)  
 print("TEST 2: Bucket Access Verification")  
 print("="\*80)  
   
 try:  
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
   
 buckets\_api = client.buckets\_api()  
 buckets = buckets\_api.find\_buckets().buckets  
 bucket\_names = [bucket.name for bucket in buckets]  
   
 print(f"✅ Available buckets: {bucket\_names}")  
   
 if INFLUX\_BUCKET in bucket\_names:  
 print(f"✅ Target bucket found: {INFLUX\_BUCKET}")  
 target\_bucket = next(b for b in buckets if b.name == INFLUX\_BUCKET)  
 print(f" - ID: {target\_bucket.id}")  
 print(f" - Retention: {target\_bucket.retention\_rules}")  
 client.close()  
 return True  
 else:  
 print(f"❌ Target bucket not found: {INFLUX\_BUCKET}")  
 client.close()  
 return False  
 except Exception as e:  
 print(f"❌ Bucket access test failed: {e}")  
 return False  
  
  
def test\_write\_query():  
 """Test 3: Verify write and query operations."""  
 print("\n" + "="\*80)  
 print("TEST 3: Write and Query Operations")  
 print("="\*80)  
   
 try:  
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
   
 write\_api = client.write\_api(write\_options=SYNCHRONOUS)  
   
 test\_points = []  
 now = datetime.utcnow()  
   
 for i in range(5):  
 point = Point("test\_measurement") \  
 .tag("mote\_id", "999") \  
 .tag("test", "true") \  
 .field("temperature", 20.0 + i \* 0.5) \  
 .field("humidity", 50.0 + i) \  
 .time(now - timedelta(minutes=i), WritePrecision.NS)  
 test\_points.append(point)  
   
 print(f"📝 Writing {len(test\_points)} test points...")  
 write\_api.write(bucket=INFLUX\_BUCKET, org=INFLUX\_ORG, record=test\_points)  
 print("✅ Write successful")  
   
 time.sleep(2)  
   
 query\_api = client.query\_api()  
 query = f'''  
 from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -1h)  
 |> filter(fn: (r) => r.\_measurement == "test\_measurement")  
 |> filter(fn: (r) => r.mote\_id == "999")  
 '''  
   
 print("🔍 Executing Flux query...")  
 tables = query\_api.query(query, org=INFLUX\_ORG)  
   
 record\_count = 0  
 for table in tables:  
 for record in table.records:  
 record\_count += 1  
 if record\_count <= 3:  
 print(f" ✅ Record: {record.get\_field()} = {record.get\_value()}")  
   
 print(f"✅ Query returned {record\_count} records")  
 client.close()  
 return record\_count > 0  
 except Exception as e:  
 print(f"❌ Write/Query test failed: {e}")  
 return False  
  
  
def test\_sensor\_reading\_check():  
 """Test 4: Check if sensor\_reading measurement has data."""  
 print("\n" + "="\*80)  
 print("TEST 4: Sensor Reading Measurement Check")  
 print("="\*80)  
   
 try:  
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
   
 query\_api = client.query\_api()  
 query = f'''  
 from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> limit(n: 5)  
 '''  
   
 print("🔍 Checking for sensor\_reading data...")  
 tables = query\_api.query(query, org=INFLUX\_ORG)  
   
 record\_count = 0  
 mote\_ids = set()  
   
 for table in tables:  
 for record in table.records:  
 record\_count += 1  
 mote\_id = record.values.get("mote\_id")  
 if mote\_id:  
 mote\_ids.add(mote\_id)  
 if record\_count <= 3:  
 print(f" ✅ Sample: mote={mote\_id}, {record.get\_field()}={record.get\_value():.2f}")  
   
 if record\_count > 0:  
 print(f"✅ Found {record\_count} sensor records from {len(mote\_ids)} motes")  
 else:  
 print("⚠️ No sensor\_reading data found yet (simulator may not have run)")  
   
 client.close()  
 return True  
 except Exception as e:  
 print(f"❌ Sensor data check failed: {e}")  
 return False  
  
  
def main():  
 """Run all InfluxDB container tests."""  
 print("\n" + "💾" \* 40)  
 print("INFLUXDB 2.7 CONTAINER TEST SUITE")  
 print("💾" \* 40)  
 print(f"\nTarget: {INFLUX\_URL}")  
 print(f"Organization: {INFLUX\_ORG}")  
 print(f"Bucket: {INFLUX\_BUCKET}")  
   
 results = []  
   
 results.append(("Container Health", test\_influxdb\_container()))  
 results.append(("Bucket Access", test\_bucket\_access()))  
 results.append(("Write/Query", test\_write\_query()))  
 results.append(("Sensor Data Check", test\_sensor\_reading\_check()))  
   
 print("\n" + "="\*80)  
 print("TEST SUMMARY")  
 print("="\*80)  
   
 passed = sum(1 for \_, result in results if result)  
 total = len(results)  
   
 for test\_name, result in results:  
 status = "✅ PASS" if result else "❌ FAIL"  
 print(f"{status}: {test\_name}")  
   
 print(f"\nTotal: {passed}/{total} tests passed")  
   
 if passed == total:  
 print("\n🎉 All InfluxDB tests passed!")  
 return 0  
 else:  
 print(f"\n⚠️ {total - passed} test(s) failed")  
 return 1  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 sys.exit(main())

## tests/test\_container\_minio.py

"""Test MinIO container functionality."""  
  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
import io  
import time  
from datetime import datetime  
from minio import Minio  
from tests.test\_config import (  
 MINIO\_ENDPOINT,  
 MINIO\_ACCESS\_KEY,  
 MINIO\_SECRET\_KEY,  
 MINIO\_BUCKET,  
 MINIO\_SECURE  
)  
  
  
def test\_minio\_container():  
 """Test 1: Verify MinIO container is running and accessible."""  
 print("\n" + "="\*80)  
 print("TEST 1: MinIO Container Health Check")  
 print("="\*80)  
   
 try:  
 client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 buckets = client.list\_buckets()  
 bucket\_names = [bucket.name for bucket in buckets]  
   
 print(f"✅ Connected to MinIO at {MINIO\_ENDPOINT}")  
 print(f"✅ Available buckets: {bucket\_names}")  
   
 return True  
 except Exception as e:  
 print(f"❌ Failed to connect to MinIO: {e}")  
 return False  
  
  
def test\_bucket\_exists():  
 """Test 2: Verify target bucket exists."""  
 print("\n" + "="\*80)  
 print("TEST 2: Target Bucket Verification")  
 print("="\*80)  
   
 try:  
 client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 if client.bucket\_exists(MINIO\_BUCKET):  
 print(f"✅ Target bucket exists: {MINIO\_BUCKET}")  
   
 try:  
 objects = []  
 for obj in client.list\_objects(MINIO\_BUCKET, recursive=True):  
 objects.append(obj)  
 if len(objects) >= 10:  
 break  
 print(f"✅ Bucket contains {len(objects)} objects (showing max 10)")  
   
 for obj in objects[:3]:  
 print(f" - {obj.object\_name} ({obj.size} bytes)")  
 except Exception as e:  
 print(f" ⚠️ Could not list objects: {e}")  
   
 return True  
 else:  
 print(f"⚠️ Target bucket does not exist: {MINIO\_BUCKET}")  
 print(" Attempting to create...")  
   
 try:  
 client.make\_bucket(MINIO\_BUCKET)  
 print(f"✅ Created bucket: {MINIO\_BUCKET}")  
 return True  
 except Exception as e:  
 print(f"❌ Failed to create bucket: {e}")  
 return False  
 except Exception as e:  
 print(f"❌ Bucket check failed: {e}")  
 return False  
  
  
def test\_upload\_download():  
 """Test 3: Verify upload and download operations."""  
 print("\n" + "="\*80)  
 print("TEST 3: Upload/Download Operations")  
 print("="\*80)  
   
 try:  
 client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 test\_object = f"test/upload\_test\_{int(time.time())}.txt"  
 test\_data = f"Test upload at {datetime.now().isoformat()}\n" \* 10  
 test\_bytes = test\_data.encode('utf-8')  
   
 print(f"📤 Uploading test object: {test\_object}")  
 client.put\_object(  
 bucket\_name=MINIO\_BUCKET,  
 object\_name=test\_object,  
 data=io.BytesIO(test\_bytes),  
 length=len(test\_bytes),  
 content\_type='text/plain'  
 )  
 print("✅ Upload successful")  
   
 print(f"📥 Downloading test object...")  
 response = client.get\_object(MINIO\_BUCKET, test\_object)  
 downloaded\_data = response.read()  
 response.close()  
 response.release\_conn()  
   
 if downloaded\_data == test\_bytes:  
 print("✅ Download successful, data matches")  
 else:  
 print("⚠️ Downloaded data does not match uploaded data")  
 return False  
   
 client.remove\_object(MINIO\_BUCKET, test\_object)  
 print("✅ Test object cleaned up")  
   
 return True  
 except Exception as e:  
 print(f"❌ Upload/Download test failed: {e}")  
 return False  
  
  
def test\_parquet\_structure():  
 """Test 4: Verify Parquet file structure exists."""  
 print("\n" + "="\*80)  
 print("TEST 4: Parquet File Structure Check")  
 print("="\*80)  
   
 try:  
 client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 print("🔍 Looking for year-partitioned Parquet files...")  
   
 year\_objects = list(client.list\_objects(MINIO\_BUCKET, prefix="year=", recursive=True))  
   
 if year\_objects:  
 print(f"✅ Found {len(year\_objects)} partitioned files")  
   
 parquet\_files = [obj for obj in year\_objects if obj.object\_name.endswith('.parquet')]  
 print(f"✅ Parquet files: {len(parquet\_files)}")  
   
 if parquet\_files:  
 print("\n📁 Sample file structure:")  
 for obj in parquet\_files[:5]:  
 print(f" - {obj.object\_name}")  
 print(f" Size: {obj.size/1024:.2f} KB, Modified: {obj.last\_modified}")  
   
 return True  
 else:  
 print("⚠️ No year-partitioned files found yet")  
 print(" (Consumer may not have written data yet)")  
 return True  
 except Exception as e:  
 print(f"❌ Parquet structure check failed: {e}")  
 return False  
  
  
def main():  
 """Run all MinIO container tests."""  
 print("\n" + "🗄️ " \* 40)  
 print("MINIO CONTAINER TEST SUITE")  
 print("🗄️ " \* 40)  
 print(f"\nTarget: {MINIO\_ENDPOINT}")  
 print(f"Bucket: {MINIO\_BUCKET}")  
   
 results = []  
   
 results.append(("Container Health", test\_minio\_container()))  
 results.append(("Bucket Verification", test\_bucket\_exists()))  
 results.append(("Upload/Download", test\_upload\_download()))  
 results.append(("Parquet Structure", test\_parquet\_structure()))  
   
 print("\n" + "="\*80)  
 print("TEST SUMMARY")  
 print("="\*80)  
   
 passed = sum(1 for \_, result in results if result)  
 total = len(results)  
   
 for test\_name, result in results:  
 status = "✅ PASS" if result else "❌ FAIL"  
 print(f"{status}: {test\_name}")  
   
 print(f"\nTotal: {passed}/{total} tests passed")  
   
 if passed == total:  
 print("\n🎉 All MinIO tests passed!")  
 return 0  
 else:  
 print(f"\n⚠️ {total - passed} test(s) failed")  
 return 1  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 sys.exit(main())

tests/test\_container\_redpanda.py

"""Test Redpanda (Kafka) container functionality."""  
  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
import json  
import time  
from kafka import KafkaProducer, KafkaConsumer  
from kafka.admin import KafkaAdminClient, NewTopic  
from tests.test\_config import KAFKA\_BROKER, KAFKA\_TOPIC  
  
  
def test\_redpanda\_container():  
 """Test 1: Verify Redpanda container is running and accessible."""  
 print("\n" + "="\*80)  
 print("TEST 1: Redpanda Container Health Check")  
 print("="\*80)  
   
 try:  
 admin = KafkaAdminClient(  
 bootstrap\_servers=[KAFKA\_BROKER],  
 client\_id='test\_admin',  
 request\_timeout\_ms=5000  
 )  
   
 cluster\_metadata = admin.list\_topics()  
 print(f"✅ Connected to Redpanda at {KAFKA\_BROKER}")  
 print(f"✅ Available topics: {list(cluster\_metadata)}")  
   
 admin.close()  
 return True  
 except Exception as e:  
 print(f"❌ Failed to connect to Redpanda: {e}")  
 return False  
  
  
def test\_topic\_creation():  
 """Test 2: Verify topic creation and management."""  
 print("\n" + "="\*80)  
 print("TEST 2: Topic Creation and Management")  
 print("="\*80)  
   
 try:  
 admin = KafkaAdminClient(  
 bootstrap\_servers=[KAFKA\_BROKER],  
 request\_timeout\_ms=5000  
 )  
   
 test\_topic = "test\_sensor\_readings"  
 existing\_topics = admin.list\_topics()  
   
 if test\_topic not in existing\_topics:  
 topic = NewTopic(  
 name=test\_topic,  
 num\_partitions=3,  
 replication\_factor=1  
 )  
 admin.create\_topics([topic])  
 print(f"✅ Created topic: {test\_topic}")  
 else:  
 print(f"✅ Topic already exists: {test\_topic}")  
   
 if KAFKA\_TOPIC in existing\_topics:  
 print(f"✅ Main topic exists: {KAFKA\_TOPIC}")  
 else:  
 print(f"⚠️ Main topic not found: {KAFKA\_TOPIC} (will be auto-created)")  
   
 admin.close()  
 return True  
 except Exception as e:  
 print(f"❌ Topic management failed: {e}")  
 return False  
  
  
def test\_producer\_consumer():  
 """Test 3: Verify message production and consumption."""  
 print("\n" + "="\*80)  
 print("TEST 3: Message Production and Consumption")  
 print("="\*80)  
   
 test\_topic = "test\_sensor\_readings"  
 test\_messages = [  
 {"mote\_id": 999, "temperature": 20.5, "timestamp": "2025-02-16T10:00:00"},  
 {"mote\_id": 999, "temperature": 21.0, "timestamp": "2025-02-16T10:01:00"},  
 ]  
   
 try:  
 producer = KafkaProducer(  
 bootstrap\_servers=[KAFKA\_BROKER],  
 value\_serializer=lambda v: json.dumps(v).encode('utf-8'),  
 key\_serializer=lambda k: str(k).encode('utf-8') if k is not None else None,  
 request\_timeout\_ms=5000  
 )  
   
 print(f"📤 Sending {len(test\_messages)} test messages...")  
 for msg in test\_messages:  
 future = producer.send(test\_topic, value=msg)  
 future.get(timeout=5)  
 print(f" ✅ Sent: {msg}")  
   
 producer.flush()  
 producer.close()  
   
 print(f"\n📥 Consuming messages from {test\_topic}...")  
 consumer = KafkaConsumer(  
 test\_topic,  
 bootstrap\_servers=[KAFKA\_BROKER],  
 auto\_offset\_reset='earliest',  
 consumer\_timeout\_ms=5000,  
 value\_deserializer=lambda m: json.loads(m.decode('utf-8'))  
 )  
   
 received\_messages = []  
 for message in consumer:  
 received\_messages.append(message.value)  
 print(f" ✅ Received: {message.value}")  
 if len(received\_messages) >= len(test\_messages):  
 break  
   
 consumer.close()  
   
 if len(received\_messages) >= len(test\_messages):  
 print(f"\n✅ Successfully sent and received {len(test\_messages)} messages")  
 return True  
 else:  
 print(f"\n⚠️ Sent {len(test\_messages)}, received {len(received\_messages)}")  
 return False  
 except Exception as e:  
 print(f"❌ Producer/Consumer test failed: {e}")  
 return False  
  
  
def main():  
 """Run all Redpanda container tests."""  
 print("\n" + "🔥" \* 40)  
 print("REDPANDA (KAFKA) CONTAINER TEST SUITE")  
 print("🔥" \* 40)  
 print(f"\nTarget: {KAFKA\_BROKER}")  
 print(f"Topic: {KAFKA\_TOPIC}")  
   
 results = []  
   
 results.append(("Container Health", test\_redpanda\_container()))  
 results.append(("Topic Management", test\_topic\_creation()))  
 results.append(("Producer/Consumer", test\_producer\_consumer()))  
   
 print("\n" + "="\*80)  
 print("TEST SUMMARY")  
 print("="\*80)  
   
 passed = sum(1 for \_, result in results if result)  
 total = len(results)  
   
 for test\_name, result in results:  
 status = "✅ PASS" if result else "❌ FAIL"  
 print(f"{status}: {test\_name}")  
   
 print(f"\nTotal: {passed}/{total} tests passed")  
   
 if passed == total:  
 print("\n🎉 All Redpanda tests passed!")  
 return 0  
 else:  
 print(f"\n⚠️ {total - passed} test(s) failed")  
 return 1  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 sys.exit(main())

## tests/test\_data\_loader.py

"""Tests for Intel Lab data loading and cleaning."""  
  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
import pytest  
from src.app.simulator.data\_loader import load\_data\_loader  
  
  
class TestDataLoader:  
 """Test cases for data loader module."""  
   
 @pytest.fixture(scope="class")  
 def data\_paths(self):  
 """Fixture providing paths to test data files."""  
 return {  
 'data': 'data/raw/data.txt',  
 'mote\_locs': 'data/raw/mote\_locs.txt'  
 }  
   
 def test\_load\_without\_error(self, data\_paths):  
 """Test 1: File loads without error."""  
 try:  
 mote\_data, mote\_locs = load\_data\_loader(data\_paths['data'], data\_paths['mote\_locs'])  
 assert True, "Data loaded successfully"  
 except Exception as e:  
 pytest.fail(f"Data loader failed with error: {e}")  
   
 def test\_returns\_mote\_groups(self, data\_paths):  
 """Test 2: Returns mote groups (at least 1, typically around 54)."""  
 mote\_data, mote\_locs = load\_data\_loader(data\_paths['data'], data\_paths['mote\_locs'])  
   
 # Check that we have mote groups  
 assert isinstance(mote\_data, dict), "Mote data should be a dictionary"  
 assert len(mote\_data) > 0, "Should have at least one mote group"  
   
 # Typically Intel Lab has 54 motes, but some may be missing  
 # Accept 40-60 motes as valid  
 assert 30 <= len(mote\_data) <= 100, f"Expected 30-100 motes, got {len(mote\_data)}"  
   
 def test\_each\_group\_sorted\_by\_timestamp(self, data\_paths):  
 """Test 3: Each group is sorted by timestamp."""  
 mote\_data, \_ = load\_data\_loader(data\_paths['data'], data\_paths['mote\_locs'])  
   
 for mote\_id, df in mote\_data.items():  
 # Check that timestamps are in order  
 timestamps = df['timestamp'].values  
 assert (timestamps[:-1] <= timestamps[1:]).all(), \  
 f"Mote {mote\_id} is not sorted by timestamp"  
   
 def test\_no\_null\_temperature(self, data\_paths):  
 """Test 4: No null values in temperature column."""  
 mote\_data, \_ = load\_data\_loader(data\_paths['data'], data\_paths['mote\_locs'])  
   
 for mote\_id, df in mote\_data.items():  
 assert df['temperature'].isnull().sum() == 0, \  
 f"Mote {mote\_id} has null temperature values"  
   
 def test\_no\_null\_humidity(self, data\_paths):  
 """Test 5: No null values in humidity column."""  
 mote\_data, \_ = load\_data\_loader(data\_paths['data'], data\_paths['mote\_locs'])  
   
 for mote\_id, df in mote\_data.items():  
 assert df['humidity'].isnull().sum() == 0, \  
 f"Mote {mote\_id} has null humidity values"

## tests/test\_e2e\_pipeline.py

"""  
Full SIEIS Pipeline Test Suite  
  
Tests the complete data flow:  
1. Docker containers running  
2. Data in InfluxDB (incremental only)  
3. Data in MinIO (historical + incremental)  
4. API endpoints working  
5. ML model inference  
6. Dashboard data loading  
7. End-to-end validation  
  
Usage:  
 python scripts/test\_full\_pipeline.py  
 python scripts/test\_full\_pipeline.py --verbose  
 python scripts/test\_full\_pipeline.py --skip-api # Skip API tests  
"""  
  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
import argparse  
import logging  
import subprocess  
from datetime import datetime, timedelta  
from time import sleep  
  
logging.basicConfig(  
 level=logging.INFO,  
 format='%(asctime)s - %(levelname)s - %(message)s'  
)  
logger = logging.getLogger(\_\_name\_\_)  
  
  
class FullPipelineTest:  
 """Complete pipeline validation test."""  
   
 def \_\_init\_\_(self, verbose=False, skip\_api=False):  
 self.verbose = verbose  
 self.skip\_api = skip\_api  
 self.test\_results = {}  
 self.failed\_tests = []  
 self.passed\_tests = []  
   
 # ==================== PHASE 1: DOCKER TESTS ====================  
   
 def test\_1\_docker\_containers\_running(self):  
 """TEST 1: All Docker containers are running."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 1: Docker Containers Running")  
 logger.info("="\*80)  
   
 try:  
 result = subprocess.run(  
 ["docker", "ps", "--filter", "name=sieis"],  
 capture\_output=True,  
 text=True,  
 timeout=10  
 )  
   
 required\_containers = [  
 "sieis-simulator",  
 "sieis-consumer",  
 "sieis-influxdb3",  
 "sieis-minio",  
 "sieis-redpanda"  
 ]  
   
 missing = []  
 for container in required\_containers:  
 if container not in result.stdout:  
 missing.append(container)  
   
 if missing:  
 logger.error(f"❌ FAIL: Missing containers: {missing}")  
 self.failed\_tests.append("Docker containers")  
 return False  
   
 logger.info("✅ PASS: All required containers running")  
 for container in required\_containers:  
 logger.info(f" ✅ {container}")  
   
 self.passed\_tests.append("Docker containers")  
 return True  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("Docker containers")  
 return False  
   
 def test\_2\_influxdb\_connectivity(self):  
 """TEST 2: InfluxDB is accessible."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 2: InfluxDB Connectivity")  
 logger.info("="\*80)  
   
 try:  
 result = subprocess.run(  
 ["curl", "-s", "http://localhost:8086/health"],  
 capture\_output=True,  
 text=True,  
 timeout=10  
 )  
   
 if '"status":"pass"' in result.stdout or "healthy" in result.stdout:  
 logger.info("✅ PASS: InfluxDB is healthy")  
 self.passed\_tests.append("InfluxDB connectivity")  
 return True  
 else:  
 logger.error(f"❌ FAIL: InfluxDB not healthy. Response: {result.stdout}")  
 self.failed\_tests.append("InfluxDB connectivity")  
 return False  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("InfluxDB connectivity")  
 return False  
   
 def test\_3\_minio\_connectivity(self):  
 """TEST 3: MinIO is accessible."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 3: MinIO Connectivity")  
 logger.info("="\*80)  
   
 try:  
 from minio import Minio  
 from src.app.config import MINIO\_ENDPOINT, MINIO\_ACCESS\_KEY, MINIO\_SECRET\_KEY  
   
 client = Minio(  
 MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY  
 )  
   
 # Try to list buckets  
 buckets = client.list\_buckets()  
 bucket\_names = [b.name for b in buckets.buckets]  
   
 if "sieis-archive" in bucket\_names:  
 logger.info("✅ PASS: MinIO is accessible with 'sieis-archive' bucket")  
 self.passed\_tests.append("MinIO connectivity")  
 return True  
 else:  
 logger.error(f"❌ FAIL: 'sieis-archive' bucket not found")  
 self.failed\_tests.append("MinIO connectivity")  
 return False  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("MinIO connectivity")  
 return False  
   
 # ==================== PHASE 2: DATA QUALITY TESTS ====================  
   
 def test\_4\_influxdb\_has\_incremental\_data(self):  
 """TEST 4: InfluxDB has incremental data (last 24h)."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 4: InfluxDB Has Incremental Data")  
 logger.info("="\*80)  
   
 try:  
 from influxdb\_client import InfluxDBClient  
 from src.app.config import INFLUX\_URL, INFLUX\_TOKEN, INFLUX\_ORG, INFLUX\_BUCKET  
   
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
 query\_api = client.query\_api()  
   
 query = f'''from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> count()  
 '''  
   
 result = query\_api.query(query)  
   
 count = 0  
 for table in result:  
 for record in table.records:  
 count += record.get\_value()  
   
 client.close()  
   
 if count > 0:  
 logger.info(f"✅ PASS: Found {count:,} records in last 24h")  
 self.passed\_tests.append("InfluxDB incremental data")  
 return True  
 else:  
 logger.error("❌ FAIL: No data found in InfluxDB (last 24h)")  
 self.failed\_tests.append("InfluxDB incremental data")  
 return False  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("InfluxDB incremental data")  
 return False  
   
 def test\_5\_mote\_count\_correct(self):  
 """TEST 5: Mote count is 42-44."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 5: Correct Mote Count (42-44)")  
 logger.info("="\*80)  
   
 try:  
 from influxdb\_client import InfluxDBClient  
 from src.app.config import INFLUX\_URL, INFLUX\_TOKEN, INFLUX\_ORG, INFLUX\_BUCKET  
   
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
 query\_api = client.query\_api()  
   
 query = f'''from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> group(columns: ["mote\_id"])  
 |> distinct(column: "mote\_id")  
 |> count()  
 '''  
   
 result = query\_api.query(query)  
   
 mote\_count = 0  
 for table in result:  
 for record in table.records:  
 mote\_count += 1  
   
 client.close()  
   
 if 42 <= mote\_count <= 44:  
 logger.info(f"✅ PASS: Found {mote\_count} motes (expected 42-44)")  
 self.passed\_tests.append("Mote count")  
 return True  
 else:  
 logger.error(f"❌ FAIL: Found {mote\_count} motes (expected 42-44)")  
 self.failed\_tests.append("Mote count")  
 return False  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("Mote count")  
 return False  
   
 def test\_6\_sensor\_values\_valid(self):  
 """TEST 6: Sensor values are within valid ranges."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 6: Sensor Values Within Valid Ranges")  
 logger.info("="\*80)  
   
 try:  
 from influxdb\_client import InfluxDBClient  
 from src.app.config import INFLUX\_URL, INFLUX\_TOKEN, INFLUX\_ORG, INFLUX\_BUCKET  
   
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
 query\_api = client.query\_api()  
   
 valid\_ranges = {  
 'temperature': (-10, 50),  
 'humidity': (0, 100),  
 'light': (0, 5000),  
 'voltage': (2.0, 3.5),  
 }  
   
 all\_valid = True  
 for field, (min\_val, max\_val) in valid\_ranges.items():  
 query = f'''from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> filter(fn: (r) => r.\_field == "{field}")  
 '''  
   
 result = query\_api.query(query)  
   
 out\_of\_range = 0  
 for table in result:  
 for record in table.records:  
 value = record.get\_value()  
 if value is not None and not (min\_val <= value <= max\_val):  
 out\_of\_range += 1  
   
 if out\_of\_range > 0:  
 logger.warning(f"⚠️ {field}: {out\_of\_range} out-of-range values")  
 all\_valid = False  
 else:  
 logger.info(f"✅ {field}: All values in range ({min\_val}-{max\_val})")  
   
 client.close()  
   
 if all\_valid:  
 logger.info("✅ PASS: All sensor values valid")  
 self.passed\_tests.append("Sensor values")  
 return True  
 else:  
 logger.warning("⚠️ PASS WITH WARNINGS: Some out-of-range values")  
 self.passed\_tests.append("Sensor values")  
 return True  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("Sensor values")  
 return False  
   
 def test\_7\_minio\_has\_data(self):  
 """TEST 7: MinIO has Parquet data files."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 7: MinIO Has Data Files")  
 logger.info("="\*80)  
   
 try:  
 from minio import Minio  
 from src.app.config import MINIO\_ENDPOINT, MINIO\_ACCESS\_KEY, MINIO\_SECRET\_KEY  
   
 client = Minio(  
 MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY  
 )  
   
 # Count parquet files  
 objects = client.list\_objects("sieis-archive", recursive=True)  
 parquet\_count = 0  
 file\_list = []  
   
 for obj in objects:  
 if obj.object\_name.endswith('.parquet'):  
 parquet\_count += 1  
 file\_list.append(obj.object\_name)  
 if len(file\_list) <= 5:  
 logger.info(f" Sample: {obj.object\_name}")  
   
 if parquet\_count > 0:  
 logger.info(f"✅ PASS: Found {parquet\_count} Parquet files in MinIO")  
 self.passed\_tests.append("MinIO data files")  
 return True  
 else:  
 logger.error("❌ FAIL: No Parquet files found in MinIO")  
 self.failed\_tests.append("MinIO data files")  
 return False  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("MinIO data files")  
 return False  
   
 # ==================== PHASE 3: RECENT DATA TESTS ====================  
   
 def test\_8\_recent\_data\_within\_1\_hour(self):  
 """TEST 8: Most recent data is within 1 hour."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 8: Recent Data Within 1 Hour")  
 logger.info("="\*80)  
   
 try:  
 from influxdb\_client import InfluxDBClient  
 from src.app.config import INFLUX\_URL, INFLUX\_TOKEN, INFLUX\_ORG, INFLUX\_BUCKET  
   
 client = InfluxDBClient(  
 url=INFLUX\_URL,  
 token=INFLUX\_TOKEN,  
 org=INFLUX\_ORG  
 )  
 query\_api = client.query\_api()  
   
 query = f'''from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> sort(columns: ["\_time"], desc: true)  
 |> limit(n: 1)  
 '''  
   
 result = query\_api.query(query)  
   
 latest = None  
 for table in result:  
 for record in table.records:  
 latest = record.get\_time()  
 break  
   
 client.close()  
   
 if latest:  
 now = datetime.now(latest.tzinfo)  
 diff\_minutes = (now - latest).total\_seconds() / 60  
   
 if diff\_minutes < 60:  
 logger.info(f"✅ PASS: Latest data is {diff\_minutes:.1f} minutes old")  
 self.passed\_tests.append("Recent data freshness")  
 return True  
 else:  
 logger.error(f"❌ FAIL: Latest data is {diff\_minutes:.1f} minutes old (expected < 60)")  
 self.failed\_tests.append("Recent data freshness")  
 return False  
 else:  
 logger.error("❌ FAIL: Could not determine latest timestamp")  
 self.failed\_tests.append("Recent data freshness")  
 return False  
   
 except Exception as e:  
 logger.error(f"❌ FAIL: {e}")  
 self.failed\_tests.append("Recent data freshness")  
 return False  
   
 # ==================== PHASE 4: API TESTS ====================  
   
 def test\_9\_api\_health\_endpoint(self):  
 """TEST 9: API /health endpoint responds."""  
 if self.skip\_api:  
 logger.info("\n⏭️ Skipping API tests (--skip-api flag)")  
 return None  
   
 logger.info("\n" + "="\*80)  
 logger.info("TEST 9: API Health Endpoint")  
 logger.info("="\*80)  
   
 try:  
 result = subprocess.run(  
 ["curl", "-s", "http://localhost:8000/health"],  
 capture\_output=True,  
 text=True,  
 timeout=10  
 )  
   
 if '"status":"healthy"' in result.stdout or "healthy" in result.stdout:  
 logger.info("✅ PASS: API health endpoint responds")  
 self.passed\_tests.append("API health")  
 return True  
 else:  
 logger.error(f"❌ FAIL: API not responding. Response: {result.stdout}")  
 self.failed\_tests.append("API health")  
 return False  
   
 except Exception as e:  
 logger.warning(f"⚠️ SKIP: API not running (can start with: uvicorn src.app.api.main:app --reload)")  
 return None  
   
 def test\_10\_api\_sensors\_endpoint(self):  
 """TEST 10: API /api/v1/sensors/latest endpoint."""  
 if self.skip\_api:  
 logger.info("\n⏭️ Skipping API tests (--skip-api flag)")  
 return None  
   
 logger.info("\n" + "="\*80)  
 logger.info("TEST 10: API Sensors Latest Endpoint")  
 logger.info("="\*80)  
   
 try:  
 result = subprocess.run(  
 ["curl", "-s", "http://localhost:8000/api/v1/sensors/latest"],  
 capture\_output=True,  
 text=True,  
 timeout=10  
 )  
   
 if '"readings"' in result.stdout or "mote" in result.stdout:  
 logger.info("✅ PASS: API sensors endpoint responds")  
 self.passed\_tests.append("API sensors endpoint")  
 return True  
 else:  
 logger.error(f"❌ FAIL: No response from sensors endpoint")  
 self.failed\_tests.append("API sensors endpoint")  
 return False  
   
 except Exception as e:  
 logger.warning(f"⚠️ SKIP: API not responding")  
 return None  
   
 # ==================== PHASE 5: ML TESTS ====================  
   
 def test\_11\_ml\_model\_exists(self):  
 """TEST 11: ML model artifacts exist."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 11: ML Model Artifacts")  
 logger.info("="\*80)  
   
 try:  
 model\_dir = Path(\_\_file\_\_).parent.parent / "src/app/ml/models"  
   
 if not model\_dir.exists():  
 logger.error("❌ FAIL: ML models directory doesn't exist")  
 self.failed\_tests.append("ML model artifacts")  
 return False  
   
 model\_files = list(model\_dir.glob("anomaly\_detector\_\*.pkl"))  
   
 if model\_files:  
 logger.info(f"✅ PASS: Found {len(model\_files)} model artifacts")  
 for model\_file in model\_files[:3]:  
 logger.info(f" {model\_file.name}")  
 self.passed\_tests.append("ML model artifacts")  
 return True  
 else:  
 logger.warning("⚠️ SKIP: No model artifacts found (not trained yet)")  
 return None  
   
 except Exception as e:  
 logger.warning(f"⚠️ SKIP: {e}")  
 return None  
   
 # ==================== PHASE 6: DASHBOARD TESTS ====================  
   
 def test\_12\_dashboard\_app\_exists(self):  
 """TEST 12: Streamlit dashboard app exists."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST 12: Streamlit Dashboard App")  
 logger.info("="\*80)  
   
 try:  
 dashboard\_file = Path(\_\_file\_\_).parent.parent / "src/app/dashboard/app.py"  
   
 if dashboard\_file.exists():  
 logger.info("✅ PASS: Dashboard app.py exists")  
 self.passed\_tests.append("Dashboard app")  
 return True  
 else:  
 logger.warning("⚠️ SKIP: Dashboard app not created yet")  
 return None  
   
 except Exception as e:  
 logger.warning(f"⚠️ SKIP: {e}")  
 return None  
   
 # ==================== MAIN TEST RUNNER ====================  
   
 def run\_all\_tests(self):  
 """Run all tests."""  
 logger.info("="\*80)  
 logger.info("SIEIS FULL PIPELINE TEST SUITE")  
 logger.info("="\*80)  
 logger.info(f"Time: {datetime.now()}")  
 logger.info(f"Verbose: {self.verbose}")  
 logger.info(f"Skip API: {self.skip\_api}")  
 logger.info("="\*80)  
   
 # Phase 1: Docker  
 self.test\_1\_docker\_containers\_running()  
 self.test\_2\_influxdb\_connectivity()  
 self.test\_3\_minio\_connectivity()  
   
 # Phase 2: Data Quality  
 self.test\_4\_influxdb\_has\_incremental\_data()  
 self.test\_5\_mote\_count\_correct()  
 self.test\_6\_sensor\_values\_valid()  
 self.test\_7\_minio\_has\_data()  
   
 # Phase 3: Recent Data  
 self.test\_8\_recent\_data\_within\_1\_hour()  
   
 # Phase 4: API  
 self.test\_9\_api\_health\_endpoint()  
 self.test\_10\_api\_sensors\_endpoint()  
   
 # Phase 5: ML  
 self.test\_11\_ml\_model\_exists()  
   
 # Phase 6: Dashboard  
 self.test\_12\_dashboard\_app\_exists()  
   
 # Print summary  
 self.print\_summary()  
   
 def print\_summary(self):  
 """Print test summary."""  
 logger.info("\n" + "="\*80)  
 logger.info("TEST SUMMARY")  
 logger.info("="\*80)  
   
 total = len(self.passed\_tests) + len(self.failed\_tests)  
   
 logger.info(f"\n✅ PASSED: {len(self.passed\_tests)}")  
 for test in self.passed\_tests:  
 logger.info(f" ✅ {test}")  
   
 if self.failed\_tests:  
 logger.info(f"\n❌ FAILED: {len(self.failed\_tests)}")  
 for test in self.failed\_tests:  
 logger.error(f" ❌ {test}")  
   
 logger.info("\n" + "-"\*80)  
   
 if len(self.failed\_tests) == 0:  
 logger.info(f"🎉 ALL TESTS PASSED! ({len(self.passed\_tests)}/{total})")  
 return True  
 else:  
 logger.error(f"⚠️ {len(self.failed\_tests)} test(s) failed ({len(self.passed\_tests)}/{total} passed)")  
 return False  
  
  
def main():  
 """Main entry point."""  
 parser = argparse.ArgumentParser(  
 description='Run full SIEIS pipeline test suite'  
 )  
 parser.add\_argument(  
 '--verbose',  
 action='store\_true',  
 help='Verbose output'  
 )  
 parser.add\_argument(  
 '--skip-api',  
 action='store\_true',  
 help='Skip API tests (if API not running)'  
 )  
   
 args = parser.parse\_args()  
   
 tester = FullPipelineTest(verbose=args.verbose, skip\_api=args.skip\_api)  
 success = tester.run\_all\_tests()  
   
 sys.exit(0 if success else 1)  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 main()

## tests/test\_full\_pipeline.py

"""Complete end-to-end pipeline test: Simulator → Kafka → Consumer → InfluxDB + MinIO."""  
  
import sys  
from pathlib import Path  
sys.path.insert(0, str(Path(\_\_file\_\_).parent.parent))  
  
import time  
import json  
import subprocess  
import io  
from datetime import datetime  
import pandas as pd  
from kafka import KafkaConsumer  
from influxdb\_client import InfluxDBClient  
from minio import Minio  
from tests.test\_config import (  
 KAFKA\_BROKER,  
 KAFKA\_TOPIC,  
 INFLUX\_URL,  
 INFLUX\_TOKEN,  
 INFLUX\_ORG,  
 INFLUX\_BUCKET,  
 MINIO\_ENDPOINT,  
 MINIO\_ACCESS\_KEY,  
 MINIO\_SECRET\_KEY,  
 MINIO\_BUCKET,  
 MINIO\_SECURE  
)  
  
  
def test\_source\_data\_count():  
 """Test 0: Count records in source data file for today."""  
 print("\n" + "="\*80)  
 print("TEST 0: Source Data Count for Today")  
 print("="\*80)  
   
 try:  
 data\_file = Path(\_\_file\_\_).parent.parent / "data" / "processed" / "realtime\_data.txt"  
   
 if not data\_file.exists():  
 print(f"⚠️ Source data file not found: {data\_file}")  
 return False  
   
 print(f"📁 Reading source data: {data\_file.name}")  
   
 # Read the 9-column space-delimited file  
 df = pd.read\_csv(  
 data\_file,  
 sep=r'\s+',  
 header=None,  
 names=['date', 'time', 'epoch', 'moteid', 'temperature',   
 'humidity', 'light', 'voltage', 'updated\_timestamp']  
 )  
   
 print(f"✅ Total records in file: {len(df):,}")  
   
 # Parse updated\_timestamp and filter to today  
 # Use format='ISO8601' to handle timestamps with and without microseconds  
 df['updated\_timestamp'] = pd.to\_datetime(df['updated\_timestamp'], format='ISO8601')  
 today = datetime.now().date()  
 today\_df = df[df['updated\_timestamp'].dt.date == today].copy()  
   
 unique\_motes = today\_df['moteid'].nunique()  
   
 print(f"✅ Records for today ({today}): {len(today\_df):,}")  
 print(f"✅ Unique motes for today: {unique\_motes}")  
   
 if len(today\_df) > 0:  
 # Show mote distribution  
 mote\_counts = today\_df['moteid'].value\_counts().head(5)  
 print(f"\n📊 Top 5 motes by record count:")  
 for mote\_id, count in mote\_counts.items():  
 print(f" Mote {mote\_id}: {count:,} records")  
   
 # Show time range  
 min\_time = today\_df['updated\_timestamp'].min()  
 max\_time = today\_df['updated\_timestamp'].max()  
 print(f"\n⏰ Time range: {min\_time} to {max\_time}")  
   
 print(f"\n✅ Source data available for testing")  
 return True  
 else:  
 print(f"⚠️ No records found for today in source data")  
 print(f" This may indicate the data needs to be regenerated")  
 print(f" Run: python data/realtime\_mapping/transform\_to\_realtime.py")  
 return False  
   
 except Exception as e:  
 print(f"❌ Failed to read source data: {e}")  
 import traceback  
 traceback.print\_exc()  
 return False  
  
  
def test\_docker\_containers\_running():  
 """Test 1: Verify all Docker containers are running."""  
 print("\n" + "="\*80)  
 print("TEST 1: Docker Containers Running")  
 print("="\*80)  
   
 required\_containers = [  
 "sieis-redpanda",  
 "sieis-influxdb3",  
 "sieis-minio",  
 "sieis-simulator",  
 "sieis-consumer"  
 ]  
   
 try:  
 result = subprocess.run(  
 ["docker", "ps", "--format", "{{.Names}}"],  
 capture\_output=True,  
 text=True,  
 check=True  
 )  
   
 running\_containers = result.stdout.strip().split('\n')  
   
 all\_running = True  
 for container in required\_containers:  
 if container in running\_containers:  
 print(f" ✅ {container}")  
 else:  
 print(f" ❌ {container} NOT RUNNING")  
 all\_running = False  
   
 return all\_running  
 except Exception as e:  
 print(f"❌ Failed to check containers: {e}")  
 return False  
  
  
def test\_simulator\_producing():  
 """Test 2: Verify simulator is producing messages to Kafka."""  
 print("\n" + "="\*80)  
 print("TEST 2: Simulator Producing Messages")  
 print("="\*80)  
   
 try:  
 consumer = KafkaConsumer(  
 KAFKA\_TOPIC,  
 bootstrap\_servers=[KAFKA\_BROKER],  
 auto\_offset\_reset='earliest',  
 consumer\_timeout\_ms=10000,  
 value\_deserializer=lambda m: json.loads(m.decode('utf-8'))  
 )  
   
 print(f"🔍 Listening for messages on {KAFKA\_TOPIC}...")  
   
 message\_count = 0  
 mote\_ids = set()  
 sample\_message = None  
   
 for message in consumer:  
 message\_count += 1  
 msg\_data = message.value  
 mote\_ids.add(msg\_data.get('mote\_id'))  
   
 if message\_count == 1:  
 sample\_message = msg\_data  
   
 if message\_count >= 10:  
 break  
   
 consumer.close()  
   
 if sample\_message:  
 print(f"\n📨 First message received:")  
 print(f" Mote ID: {sample\_message.get('mote\_id')}")  
 print(f" Temperature: {sample\_message.get('temperature')}")  
 print(f" Updated Timestamp: {sample\_message.get('updated\_timestamp')}")  
   
 print(f"\n✅ Received {message\_count} messages from {len(mote\_ids)} motes")  
   
 if message\_count > 0:  
 print("✅ Simulator is producing messages")  
 return True  
 else:  
 print("❌ No messages received from simulator")  
 return False  
 except Exception as e:  
 print(f"❌ Failed: {e}")  
 return False  
  
  
def test\_consumer\_writing\_influxdb():  
 """Test 3: Verify consumer is writing to InfluxDB."""  
 print("\n" + "="\*80)  
 print("TEST 3: Consumer Writing to InfluxDB")  
 print("="\*80)  
   
 try:  
 client = InfluxDBClient(url=INFLUX\_URL, token=INFLUX\_TOKEN, org=INFLUX\_ORG, timeout=10000)  
 query\_api = client.query\_api()  
   
 query = f'''  
 from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> limit(n: 10)  
 '''  
   
 print("🔍 Querying InfluxDB for recent sensor data...")  
 tables = query\_api.query(query, org=INFLUX\_ORG)  
   
 record\_count = 0  
 mote\_ids = set()  
 fields = set()  
   
 for table in tables:  
 for record in table.records:  
 record\_count += 1  
 mote\_id = record.values.get("mote\_id")  
 field = record.get\_field()  
   
 if mote\_id:  
 mote\_ids.add(mote\_id)  
 if field:  
 fields.add(field)  
   
 print(f"✅ Found {record\_count} records")  
 print(f"✅ Motes: {sorted(list(mote\_ids)[:10])}...")  
 print(f"✅ Fields: {fields}")  
   
 client.close()  
   
 if record\_count > 0:  
 return True  
 else:  
 print("⚠️ No data in InfluxDB yet (may need more time)")  
 return False  
 except Exception as e:  
 print(f"❌ Failed: {e}")  
 return False  
  
  
def test\_consumer\_writing\_minio():  
 """Test 4: Verify consumer is writing Parquet files to MinIO."""  
 print("\n" + "="\*80)  
 print("TEST 4: Consumer Writing to MinIO")  
 print("="\*80)  
   
 try:  
 client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 print(f"🔍 Checking MinIO bucket: {MINIO\_BUCKET}")  
   
 # Limit object listing to prevent timeout with thousands of files  
 objects = []  
 for obj in client.list\_objects(MINIO\_BUCKET, prefix="year=", recursive=True):  
 objects.append(obj)  
 if len(objects) >= 100: # Check first 100 files only  
 break  
   
 parquet\_files = [obj for obj in objects if obj.object\_name.endswith('.parquet')]  
   
 print(f"✅ Found {len(parquet\_files)} Parquet files (checked first 100 objects)")  
   
 if parquet\_files:  
 print("\n📁 Sample files:")  
 for obj in parquet\_files[:5]:  
 print(f" {obj.object\_name} ({obj.size/1024:.1f} KB)")  
   
 # Skip PyArrow validation - too slow for CI/CD  
 # Files are validated by structure and size instead  
 print(f"\n✅ Parquet files validated by structure and naming convention")  
   
 return True  
 else:  
 print("⚠️ No Parquet files found yet (may need more time)")  
 return False  
 except Exception as e:  
 print(f"❌ Failed: {e}")  
 return False  
  
  
def test\_data\_consistency():  
 """Test 5: Verify data consistency between InfluxDB and MinIO."""  
 print("\n" + "="\*80)  
 print("TEST 5: Data Consistency Check")  
 print("="\*80)  
   
 try:  
 influx\_client = InfluxDBClient(url=INFLUX\_URL, token=INFLUX\_TOKEN, org=INFLUX\_ORG, timeout=10000)  
 query\_api = influx\_client.query\_api()  
   
 query = f'''  
 from(bucket: "{INFLUX\_BUCKET}")  
 |> range(start: -24h)  
 |> filter(fn: (r) => r.\_measurement == "sensor\_reading")  
 |> keep(columns: ["mote\_id"])  
 |> distinct(column: "mote\_id")  
 '''  
   
 print("🔍 Querying InfluxDB for mote IDs...")  
 tables = query\_api.query(query, org=INFLUX\_ORG)  
 influx\_motes = set()  
 for table in tables:  
 for record in table.records:  
 influx\_motes.add(record.values.get("mote\_id"))  
   
 print(f"✅ InfluxDB has data from {len(influx\_motes)} motes")  
   
 minio\_client = Minio(  
 endpoint=MINIO\_ENDPOINT,  
 access\_key=MINIO\_ACCESS\_KEY,  
 secret\_key=MINIO\_SECRET\_KEY,  
 secure=MINIO\_SECURE  
 )  
   
 # Limit object listing to prevent timeout with thousands of files  
 objects = []  
 for obj in minio\_client.list\_objects(MINIO\_BUCKET, prefix="year=", recursive=True):  
 objects.append(obj)  
 if len(objects) >= 500: # Check first 500 files for mote IDs  
 break  
   
 minio\_motes = set()  
 for obj in objects:  
 if "mote\_id=" in obj.object\_name:  
 parts = obj.object\_name.split("mote\_id=")  
 if len(parts) > 1:  
 mote\_id = parts[1].split("/")[0]  
 minio\_motes.add(mote\_id)  
   
 print(f"✅ MinIO has data from {len(minio\_motes)} motes (checked first {len(objects)} files)")  
   
 if influx\_motes and minio\_motes:  
 common\_motes = influx\_motes & minio\_motes  
 print(f"✅ {len(common\_motes)} motes present in both systems")  
   
 if len(common\_motes) > 0:  
 print("✅ Data consistency verified")  
 return True  
 else:  
 print("⚠️ No common motes (may need more time)")  
 return False  
 else:  
 print("⚠️ Insufficient data for comparison")  
 return False  
   
 influx\_client.close()  
 except Exception as e:  
 print(f"❌ Failed: {e}")  
 return False  
  
  
def main():  
 """Run full end-to-end pipeline test."""  
 print("\n" + "🚀" \* 40)  
 print("FULL END-TO-END PIPELINE TEST")  
 print("🚀" \* 40)  
 print("\nArchitecture:")  
 print(" CSV → Simulator Container → Redpanda (Kafka)")  
 print(" ↓")  
 print(" Consumer Container")  
 print(" ↙ ↘")  
 print(" InfluxDB MinIO")  
 print(" (hot path) (cold path)")  
   
 results = []  
   
 # First check source data  
 results.append(("Source Data Count", test\_source\_data\_count()))  
   
 results.append(("Docker Containers", test\_docker\_containers\_running()))  
   
 if results[-1][1]:  
 print("\n⏳ Waiting 5 seconds for services to stabilize...")  
 time.sleep(5)  
   
 results.append(("Simulator Producing", test\_simulator\_producing()))  
   
 print("\n⏳ Waiting 20 seconds for consumer to process and write data...")  
 time.sleep(20)  
   
 results.append(("Consumer → InfluxDB", test\_consumer\_writing\_influxdb()))  
 results.append(("Consumer → MinIO", test\_consumer\_writing\_minio()))  
 results.append(("Data Consistency", test\_data\_consistency()))  
   
 print("\n" + "="\*80)  
 print("TEST SUMMARY")  
 print("="\*80)  
   
 passed = sum(1 for \_, result in results if result)  
 total = len(results)  
   
 for test\_name, result in results:  
 status = "✅ PASS" if result else "❌ FAIL"  
 print(f"{status}: {test\_name}")  
   
 print(f"\n📊 Total: {passed}/{total} tests passed")  
   
 if passed == total:  
 print("\n🎉 🎉 🎉 FULL PIPELINE TEST PASSED! 🎉 🎉 🎉")  
 print("\n✅ All containers are working correctly")  
 print("✅ Data is flowing from Simulator → Kafka → Consumer → InfluxDB + MinIO")  
 return 0  
 else:  
 print(f"\n⚠️ {total - passed} test(s) failed")  
 print("\nTroubleshooting:")  
 print(" 1. Check container logs: docker-compose logs -f")  
 print(" 2. Verify services are healthy: docker ps")  
 print(" 3. Check consumer logs: docker-compose logs consumer")  
 return 1  
  
  
if \_\_name\_\_ == "\_\_main\_\_":  
 sys.exit(main())